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The front-cover illustration shows one of the Krystal crystallisers in a triple-effect plant, installed in Australia, engineered by The Power-Gas Corporation Ltd. This process is the only truly continuous one for producing crystals by evaporation, cooling or chemical reaction, either separately or in combination.

Classified Advertisements, after page 834

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FACTEURS DANS LE DESSIN DES CRISTALLISATEURS CONTINUS

par S. H. Branson, Ph.D., A.M.I.Chem.E.

Le dessin des cristallisateurs continus doit se réaliser empiriquement. L'article montre que si l'on possède des données sur la vitesse de croissance des cristaux sous une certaine forme, les analyses peuvent se faire dans les cas de classification complète en fonction de la dimension, dans les cas d'absence de classification et dans les cas de classification partielle.

B.C.E., 5, 12, 845. U.D.C. No. 66.012.4:66.097.

UNE METHODE RIGOUREUSE POUR DETERMINER LES ETAGES DES REACTEURS

par G. Narsimhan et L. K. Doraiswamy

On a mis au point une méthode rigoureuse pour évaluer les résistances individuelles que l'on rencontre dans un réacteur chimique constitué d'un fluide s'écoulant sur un catalyseur solide. L'équation que l'on suggère pour obtenir la hauteur de chaque étage du réacteur tient compte des résistances à la diffusion des agents réagissants et des produits de la réaction et de la résistance à la réaction chimique superficielle qui peuvent être de n'importe quelle ordre de grandeur.

Lorsqu'on estime la résistance à la diffusion des produits, on tient compte de l' "efficacité de contact" du catalyseur qui traduit l'écart du point d'équilibre de la réaction chimique superficielle. La méthode est illustrée par des calculs de hauteurs des divers étages des réacteurs dans un convertisseur à SO_2 à l'aide des données expérimentales tirées des publications.

B.C.E., 5, 12, 849. U.D.C. No. 66-498.2:532.3.

CARACTERISTIQUES D'ECOULEMENT DE SUSPENSIONS DILUEES A PETITES PARTICULES

par R. C. Cairns, A.S.T.C. (Chem. Eng.), B.Sc., Ph.D., K. R. Lawther, B.Sc., B.E., Ph.D., et K. S. Turner, A.S.T.C. (Chem. Eng.), M.Sc.

Dans une étude sur la théorie, qui n'a pas encore été développée, des suspensions à fines particules, les auteurs ont examiné les profils de concentration des particules dans des suspensions s'écoulant à travers des tuyaux horizontaux et verticaux. Ils ont conclu, entre autres, de ces travaux, que la vélocité de sédimentation est presque indépendante de la concentration en circulation, et que les nombres de Reynolds appliqués à la masse ne mesurent ni la turbulence ni le degré de suspension. Ils proposent une corrélation pour les vélocités de sédimentation des particules de dimensions allant de 240 à 380 microns.

B.C.E., 5, 12, 857. U.D.C. No 66.048.52.

PERFORMANCE D'UN EVAPORATEUR A COUCHES MINCES MONTANTES

par J. C. R. Turner

L'évaporateur utilisé est à tube unique et emploi des différences de températures allant jusqu'à 60° F. (15,6° C.). On s'est servi de tubes de trois longueurs et de deux diamètres différents. On a constaté que les taux de vapeur sont indépendants de l'immersion lorsqu'il n'y a pas séchage, ce dernier produisant une chute prononcée dans le coefficient de transfert de chaleur général.

B.C.E., 5, 12, 860. U.D.C. No. 665.36.061.51: 664.1.03.

PROGRES DANS L'EXTRACTION DE LA CIRE DE CANNE A SUCRE

par J. Pominski et B. M. Kopacz

On a montré, en laboratoire, que les principes d'extraction par filtrage peuvent être appliqués avec succès à la boue de sucre de canne pour produire de la cire brute de sucre de canne. Les boues de sucre de canne soumises à ce procédé ont des vélocités de masse allant jusqu'à 5.900 lbs/hr./sq. ft. (28.806 kg/hr./m²) et donnent des cires brutes de sucre de canne pouvant être récupérés en grande partie. Les expériences de petite envergure montrent clairement qu'il est nécessaire d'entreprendre des travaux complémentaires plus importants.

Kurzreferate

B.C.E., 5, 12, 838. U.D.C. No. 66.065.52.

KONSTRUKTIONSFAKTOREN FÜR KONTINUIERLICHE KRISTALLISATOREN

von Dr. phil. S. H. Branson, A.M.I.Chem.E.

Die Konstruktion kontinuierlich arbeitender Kristallisatoren muss empirisch bestimmt werden. Der Artikel zeigt, dass, wenn Daten über das Wachstum der Kristalle vorhanden sind, Konstruktionsanalysen für komplette Grössenklassifizierung, Nichtklassifizierung und teilweise Grössenklassifizierung durchgeführt werden können.

B.C.E., 5, 12, 845. U.D.C. No. 66.012.4:66.097.

GENAUE REAKTORENKONSTRUKTIONEN

von G. Narsimhan und L. K. Doraiswamy

Ein genaues Verfahren wurde entwickelt zur Bestimmung der Einzelwiderstände in einem chemischen Reaktor, in welchem eine Flüssigkeit über einen festen Katalysator fliesst. Die vorgeschlagene Gleichung für die Höhe des Reaktors berücksichtigt auch den Diffusionswiderstand der Reagenzien, Produkte und den Widerstand gegen die chemische Oberflächenreaktion.

Bei der Bestimmung des Diffusionswiderstands der Produkte wird die Kontaktleistung des Katalysators berücksichtigt, welche ein Mass für die Abweichung vom Gleichgewicht der chemischen Oberflächenreaktion darstellt. Das Verfahren wird durch die Bestimmung der individuellen Höhe eines SO_2-Konverters illustriert, wobei experimentelle Daten aus der Literatur benützt werden.

B.C.E., 5, 12, 849. U.D.C. No. 66-498.2:532.3.

STRÖMUNGSKENNLINIEN VON VERDÜNNTEN KLEINSTPARTIKEL-SUSPENSIONEN

von R. C. Cairns, A.S.T.C. (Chem. Eng.), B.Sc., Ph.D., K. R. Lawther, B.Sc., B.E., Ph.D., und K. S. Turner, A.S.T.C. (Chem. Eng.), M.Sc.

In einem Beitrag zur noch unentwickelten Theorie der Kleinstpartikel-Suspensionen untersuchten die Verfasser Profile von Partikelkonzentrationen in Suspensionen durch horizontale und vertikale Rohre. Zufolge den von den Autoren erarbeitetem Schlüssen sind die Setzungsgeschwindigkeiten von der umlaufenden Konzentration fast unabhängig und Gesamt-Reynolds-Nummern messen weder die Turbulenz noch den Suspensionsgrad. Eine Korrelation wird vorgeschlagen für die Setzungsgeschwindigkeiten von Partikeln im Bereich von 240–380 μ.

B.C.E., 5, 12, 857. U.D.C. No 66.048.52.

DIE LEISTUNG EINES SCHWERKRAFT-BETÄTIGTEN KLETTERVERDAMPFERS

von J. C. R. Turner

Der Verdampfer war ein Einröhrenverdampfer mit einer Gesamttemperaturdifferenz von bis zu 15,6° C. Drei verschiedene Rohrlängen mit zwei verschiedenen Durchmessern wurden benützt. Der Dampfdurchfluss war von der Tauchung in Abwesenheit von Austrocknung unabhängig, in welchem Falle sich ein scharfes Abfallen des gesamten Wärmeübertragungskoeffizienten bemerkbar machte.

B.C.E., 5, 12, 860. U.D.C. No. 665.36.061.51: 664.1.03.

EXTRAKTION VON ZUCKERROHRWACHS

von J. Pominski und B. M. Kopacz

Wie durch Laboratoriumsteste bewiesen, lassen sich die Grundsätze der Filter-Extraktion erfolgreich mit Zuckerrohrschlamm zur Herstellung von rohem Zuckerrohrwachs anwenden. Diesem Verfahren unterworfene Zuckerrohrschlämme haben Massengeschwindigkeiten von bis zu 28.800 kg/h/m² und ergeben rohe Zuckerrohrwachse mit hohem Ertragsfaktor. Die auf kleinem Massstab durchgeführten Experimente zeigen die Notwendigkeit weiterer Arbeiten auf grösserem Massstab.

Резюме

B.C.E., 5, 12, 838. U.D.C. No. 66.065.52.

ФАКТОРЫ КОНСТРУКЦИИ НЕПРЕРЫВНЫХ КРИСТАЛЛИЗАТОРОВ

С. Х. Брансон.

Конструкция непрерывных кристаллизаторов должна осуществляться эмпирически. В статье показывается, что при наличии в каком либо виде данных о степени образования кристаллов, можно делать анализ конструкции при полной классификации размеров, неклассификации и частичной классификации размеров.

B.C.E., 5, 12, 845. U.D.C. No. 66.012.4:66.097.

СТРОГИЙ ПОДХОД К МЕТОДАМ ПРОЕКТИРОВАНИЯ РЕАКТОРОВ

Г. Нарсимхан и Л. Г. Дорайзвами.

Объясняются строгие методы для определения отдельного сопротивления в химическом реакторе, состоящем из жидкости текущей по твердому катализатору. Предлагаемое уравнение для высоты реактора, учитывает сопротивления диффузии стабилизирующих веществ продуктов и сопротивление поверхностной химической реакции, которая может быть какой угодно степени.

При определении сопротивления продуктов диффузии, следует учитывать «контактную эффективность» катализатора, которая является мерилом отклонения от равновесия химической реакции на поверхности. Этот метод иллюстрируется при помощи подсчета разных отдельных высоты для конвертера SO_2, используя экспериментальные данные технической литературы.

B.C.E., 5, 12, 849. U.D.C. No. 66-498.2:532.3.

ХАРАКТЕРНЫЕ ЧЕРТЫ ПОДВЕШАННЫХ В ЖИДКОСТИ РАЗЖИЖЕННЫХ МЕЛКИХ ЧАСТИЦ

Р. С. Кэрнс, К. Р. Лоутер и К. С. Тэрнер.

Внося свой вклад в неразработанную еще теорию суспензий мелких частиц, авторы статьи рассматривали изменения концентрации частиц, находящихся в подвешанном состоянии и протекающих по горизонтальным и вертикальным трубам. В результате, авторы статьи достигли в частности заключения, что скорость осаждения почти независима от концентрации циркулирующего потока, и что валовые Рейнольдса числа не измеряют ни турбулентности ни степени суспензии. Предлагается корреляция для стабилизации скорости осаждения частиц между 240 и 380 микронов.

B.C.E., 5, 12, 857. U.D.C. No 66.048.52.

РАБОЧИЕ КАЧЕСТВА ИСПАРИТЕЛЯ С ПОДНИМАЮЩЕЙСЯ ПЛЕНКОЙ И С ГРАВИТАЦИОННЫМ ПИТАНИЕМ

Дж. С. Р. Тэрнер.

Речь идет об испарителе с одной трубой, применяющим общеразличия температуры до 15.6° С. Были испробованы три трубы различной длины, двух различных диаметров. Количество пара не зависило от погружения при отсутствии высушивания, которое вызвала резкое понижение общего коэффициента теплопередачи.

B.C.E., 5, 12, 860. U.D.C. No. 665.36.061.51: 664.1.03.

УСОВЕРШЕНСТВОВАНИЯ В ОБЛАСТИ ИЗВЛЕЧЕНИЯ ВОСКА САХАРНОГО ТРОСТНИКА

Дж. Поминский и Б. М. Копач.

В лабораторном масштабе удалось доказать, что принципы фильтрации — извлечения можно успешно применить к грязи сахарного тростника, получая таким образом неочищенный воск сахарного тростника. Грязь сахарного тростника подвергаясь этому процессу достигает массовой скорости до 5.900 фунт/в час/кв. фут и дает неочищенный воск сахарного тростника с высокой эффективностью выделения. Эксперименты в малом масштабе указывают на необходимость дальнейшей исследовательской работы над экспериментами в более широком масштабе.

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Science and Engineering

ENGINEERING sciences differ from natural sciences in their objective, which is to help design and construction, whereas natural sciences are concerned with the study of natural phenomena. In developing this theme of the contribution of science to mechanical engineering* Professor OWEN A. SAUNDERS, indicated that he preferred to use the term 'technology' to describe the branches of knowledge which have grown more specifically around specialised engineering activities such as fuel technology or nuclear chemical technology. Discussing the relation between the forms of activity, Professor SAUNDERS spoke of the attraction of heat-transfer work where the results are useful both in new engineering developments such as nuclear reactors and in older plants such as boilers, condensers and all types of industrial heat-exchangers. As a specific example the President referred to the importance of natural convection in gases at high pressure. Difficulties had been found with the heating in a hydrogenation plant due to failure to realise that in hydrogen at high pressure free convection currents will occur in extremely narrow gaps of a small fraction of an inch. A more recent subject is the convective heat-transfer from heated rotating surfaces such as cylinders and discs. No systematic work was done in this field until about 1951 although heat transfer from rotating surfaces introduces some interesting new problems.

A novel off-shoot of work on transfer of heat (quoted in the same address) has been the design by MR. D. T. SHORE of a heat exchanger for cooling and controlling the blood temperature which has in the last few months been successfully used at Westminster Hospital for a surgical operation on a patient's heart. This is said to open up new possibilities for cardiac surgery by giving the surgeon much longer time for his work.

* Presidential Address to the Institution of Mechanical Engineers.

Sampling From Process Columns

IN addition to its primary function of examining optimum conditions for oil-to-coal conversion, research on the Fischer-Tropsch reaction—scheduled for closure if Wilson Committee findings are endorsed—has also yielded a number of interesting off-shoots. Three of the patent applications recently announced by the National Research Development Corporation stem from this part of the Warren Spring Laboratory programme. One provides a method of withdrawing from process columns containing solid, liquid and gas, samples of liquid free from both gas and solid particles, without the use of a pump. The invention is essentially a loop connected to the vessel containing the gas-liquid column at two points at different levels in such a way that substantially gas-free liquid flows downwards naturally through the loop and returns to the bottom of the column. To prevent entrainment of gas in the liquid recirculating through the loop the off-take pipe at the higher level is inclined downwards from the main column to the loop. The effective density of the liquid in the main column is reduced because of the gas bubbling through it and this makes it possible to provide natural external recirculation of the liquid. This recirculation device can include a manometer chamber for detecting the level of liquid in the main column. It can have a filter chamber for withdrawing filtered liquid from the column and can be used for monitoring or controlling the performance of the chemical process column.

In the course of work on filtering the liquid obtained, a technique for making a pre-compressed pack filter was developed giving a full length compressed filter candle which will retain its high filtering efficiency for long periods. Furthermore the filtering efficiency can be restored after it has suffered the normal gradual decline in use. A further invention is a froth breaker comprising a continuous helical surface in which each convolution is of a generally conical shape. The structure is so mounted that it can easily be removed from its chamber if necessary for cleaning.

Any enquiries about these developments should be addressed to NRDC at 1, Tilney St., London, W.1.

Corrosion by Nitric Acid at Stainless Steel Welds

LAST February (p. 78) we referred to work by MICHEL L. J. BERNARD, Head of Laboratory at the Société d'Etude de la Propulsion par Réaction, on the selection of metals capable of resisting fuming nitric acid. DR. BERNARD has now published* the results of tests on welds made in two types of austenitic 18-8 stainless steels, in a programme designed to follow up the earlier work. Steels selected for consideration were those of low carbon and those stabilised with titanium. Samples taken from plant were examined, while others were exposed to attack under hot or cold conditions, and in thermal cycles. Both in practical use and in laboratory tests, the steels of low carbon content gave very good results. These were steels meeting a specification of 17/20 per cent chromium, 9/13 per cent nickel, 2 per cent manganese, 1 per cent silicon and carbon not more than 0.04 per cent. Resistance to intergranular corrosion at the level of the welds in fuming nitric acid was excellent in the cold, good in the hot. Samples with carbon contents between 0.025 per cent and 0.030 per cent were considered to be immune to intergranular attack by fuming nitric acid. The use of titanium-stabilised steel for this application is not considered advisable since a new type of intergranular corrosion appears which the author calls the "knife-blade" type. Steels of this type investigated were those meeting a specification generally identical to that listed above but having 0.12 per cent carbon (instead of 0.04 per cent maximum) and 0.40 per cent titanium. A possible way of overcoming the liability to corrosion would be by heat treatment after welding but this was not investigated.

* *Corrosion et Anticorrosion*, Vol. 8, No. 10, 1960, p. 359.

Using Continuous Process Chromatography

THE main objection to using a continuous chromatograph for closed-loop process control has been that it gives a batch type analysis and only an intermittent indication of component concentration. In a recent symposium on quality control*, D. J. FRAADE of Consolidated Electrodynamics Corporation, gave an example of a successful application of control based upon stream analysis following the development of high-speed chromatography. Analysis cycles were cut from about 10 to 20 minutes to periods of about one minute or less for components through the C_5 range. The need for key component peak storage between analyses was met by commercially available memory devices suitable for either pneumatic or electronic control instrumentation. One of the most widespread applications had been in natural gasoline plants. For example the Reef Corporation of Texas have applied a process chromatograph and a pneumatic control system to their fractionating train. In this system, the analyser samples the bottom product of the de-ethaniser for ethane as an impurity, and controls the ethane content to a feasible and allowable maximum so that the overhead propane product from a depropaniser downstream meets a vapour pressure specification.

With this type of plant, revenue is gained by the sale of the liquefied natural gas products removed from the gas in the oil wells. The uncondensed portion of the gas is also sold, but the ethane content is here worth only 0.39 cents per gallon as against 40 cents when sold as a propane product. The increase of 2 per cent in the ethane content of the propane product achieved was sufficient to recover the cost of the control system in six months.

* Organised by Elliott Bros. (London) Ltd.

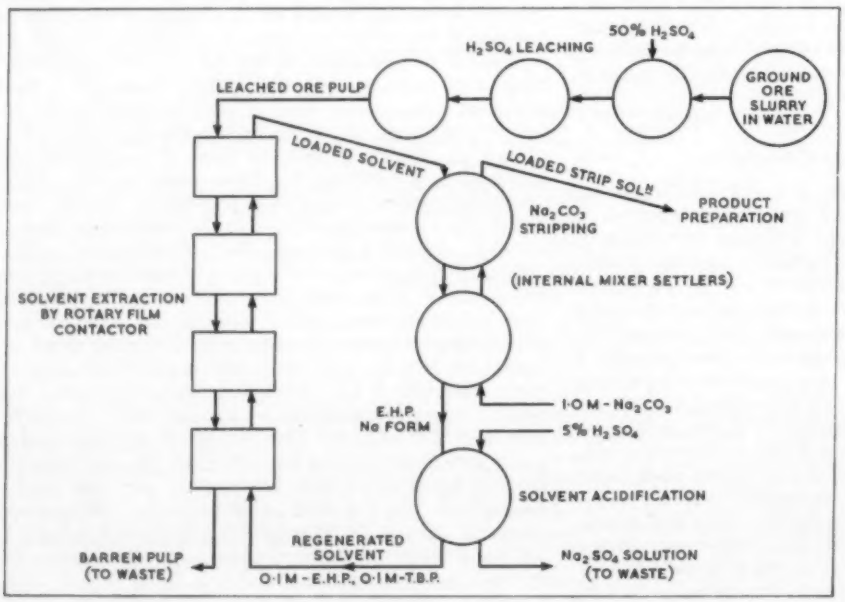
Hydro-metallurgy at National Chemical Laboratory

APPLICATIONS of crushing, grinding, classification, leaching with mechanical or air agitation, filtration, clarification, ion-exchange, solvent extraction, precipitation may all now be investigated at the National Chemical Laboratory on a scale of up to one ton of ore per day. A new wing for technical scale studies is equipped to carry out all aspects of hydrometallurgical research. At the recent Open Day of the laboratory we saw a novel pulp film contactor for solvent extraction of metal values from unfiltered leach slurries. Background to the development is the difficulty in phase disengagement in conventional types of contactor which therefore cannot be used for the solvent extraction of solutes from slurries since solvent losses by entrainment are economically prohibitive. The new device has been designed to provide adequate interfacial area per unit volume for mass transfer without actually dispersing one phase in the other. Thus solutes can be extracted directly from slurries obviating the usual considerable expenditure on liquid/solid separation.

Each contactor consists essentially of a tank in which are a number of discs on a common horizontal shaft. The discs are rotated and thereby both maintain solids in suspension in the pulp occupying the lower third of the contactor, and carry a film of pulp through the upper solvent layer. For demonstration the rotary film contactors were being used for the continuous countercurrent solvent extraction of uranium from an ore pulp of approximately 50 per cent solids leached with sulphuric acid. The solvent is a solution of di-(2-ethylhexyl) hydrogen phosphate in kerosene modified by the addition of tributyl phosphate. Uranium is stripped from the loaded solvent by contact with a molar solution of sodium carbonate in internal mixer-settlers. The stripped solvent is brought into contact with sulphuric acid to regenerate the hydrogen form of the alkyl phosphate, then recycled to the rotary film contactor. The simple flow diagram which this makes possible is shown below.

Hydrodynamics of Liquid Films on a Vertical Plate

FOR more than thirty years the wetted wall column has been used for determining mass transfer coefficients. The popularity of this apparatus was due to the belief that the interfacial area was known. In fact waves occur in the liquid film. It is evident that if the interfacial area is greatly altered by the existence of these waves the mass transfer coefficients determined in this type of apparatus will be in error. Fresh light has been shed on this problem by the results of an investigation by S. PORTALSKI *et al.* of the critical Reynolds Number for wave inception and the increase in surface area thus produced. A theoretical



Flow diagram of Solvent Extraction From Leached Ore Pulp Using Rotary Film Contactor. E.P.H. = di-(2-ethylhexyl) hydrogen phosphate. T.B.P. = tributyl phosphate.

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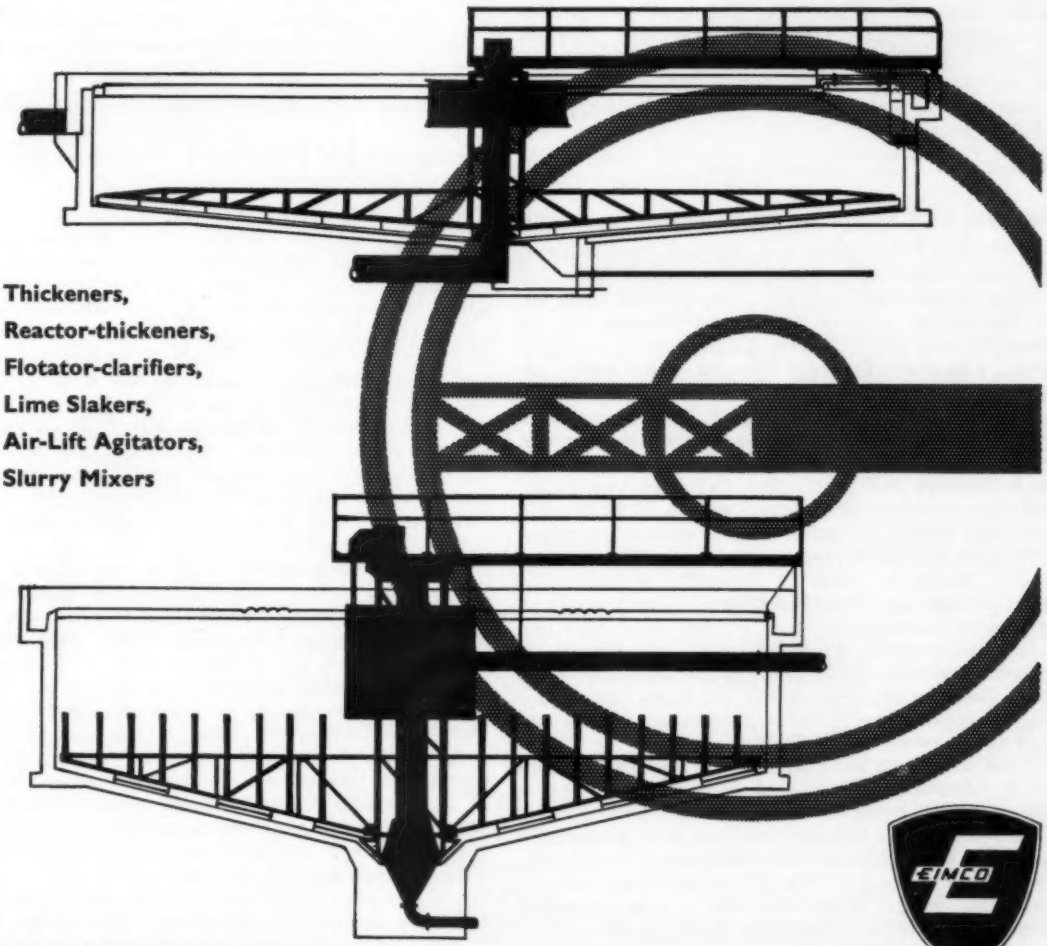

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P.2699

study based on Kapitsa's development of the Navier-Stokes equation was followed by experimental determinations in an apparatus with two novel features. The film thickness was measured by the use of capacitometers which were not in contact with the film, and consequently did not interfere with the flow. In addition, a special device enabled the hold-up on a large plate to be accurately weighed as an independent check. In a joint paper* with DR. S. R. TAILBY, DR. PORTALSKI reported that using a film of 82 per cent (by wt) glycerine solution he had demonstrated the existence of a critical Reynolds number for wave inception (Re^i). For these conditions the theoretical value of Re_i was 4.9. Photographs showed the value to be 7.0 and these two values were considered to be in good agreement.

On theoretical grounds it was considered that increase in interfacial area due to wave motion might amount to nearly 150 per cent at values of Reynolds Number of around 700 for a highly mobile liquid such as 2-propanol. The only experimental check reported however was at a very much lower figure. Again using 82 per cent glycerine and measuring the length of the wave profile it was shown that the increase in interfacial area is in the region of 3 per cent showing good agreement with a calculated value of 3.3 per cent.

* Presented to the Symposium on Surface Effects and Liquid Behaviour organised by the Institution of Chemical Engineers.

Progress in Cryogenic Engineering

MORE than 750 scientists and engineers from industry, government, and universities attended the 1960 Cryogenic Engineering Conference recently held under the joint sponsorship of the Boulder Laboratories of the National Bureau of Standards and Colorado University at Boulder, Colorado. The NBS has now issued a brief report* of the main subjects discussed. Papers included a description by P. D. FULLER and W. E. GIFFORD of a highly successful plant for producing liquid hydrogen from refinery waste gas. The plant, having sections dealing with purification and liquefaction, had given continuous, relatively trouble-free performance periods of 24 hours a day, 7 days a week, for up to 67 days without shutdown. In the same session devoted to processes, experiments by the U.S. Bureau of Mines on the explosion hazards of liquid hydrogen were discussed by M. G. ZABETAKIS *et al.* The greatest hazards found in this study were those due to the freezing of air in liquid hydrogen, the ignition of confined flammable hydrogen-air mixtures and those arising from the rapid production of flame and radiant energy following ignition of the hydrogen-air mixtures above a spill area.

At the session on physical equilibria, several methods used to compute the vapour phase composition and to predict its equilibrium in a pressurised, two-component system consisting of hydrogen-methane were presented in a paper by B. S. KIRK and his colleagues of the Georgia Institute of Technology. The work assumed an equation of state for the gas phase, and used as a parameter the "enhancement factor." This was defined as the ratio of the partial pressure to the vapour pressure of the condensed component.

The report gives only brief notes on these and other papers but generally provides sufficient information to enable the reader to decide which subjects may be of value; the relevant organisations are named so that it is possible to follow up with further enquiries if desired. In addition proceedings will be published as "Advances in Cryogenic Engineering, Volume 6," due to be available from Plenum Press, Inc., early in 1961.

* Summary Technical Report STR-2524. U.S. Department of Commerce. National Bureau of Standards, Washington 25 D.C., U.S.A.

Prospects of Trade with Roumania

"FROM recent discussions in Bucharest and from a study of the economic plans for the next few years, it would seem that the British industries most likely to find scope in the Roumanian market are:

Chemical industry—Complete plants with or without "know-how", specialised components for the chemical industry, especially in the field of petrochemicals.

Plastics industry—The Roumanians will be interested in acquiring further "know-how" for the production of certain plastics raw materials together with either complete plants or major sections of plants. A wide range of plastics machinery for the production of industrial goods as well as consumer items will be required.

Automation and control mechanisms—for a variety of industries."

Extract from Report of visit to Roumania by The Director of the British Council for the Promotion of International Trade.

Designing for Adiabatic Absorption of HCl

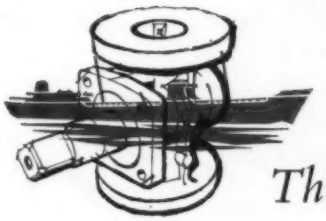
FOR making hydrochloric acid solution by absorbing the gas in water there are three principal processes available. If the heat of solution is removed through heat exchange surfaces the absorption may be carried out purely isothermally; alternatively the heat may be taken up as sensible heat in the liquid and removed by cooling of the acid outside the apparatus leading to partially isothermal conditions. Finally, the heat may be removed within the apparatus by evaporation of water, without heat exchange in a cooling system. There are great advantages in this adiabatic system of absorption—simpler plant, absence of heat exchange surfaces and the need for cooling water, and greater flexibility. Furthermore, if the HCl gas is being obtained from organic chlorinations volatile organic impurities are removed with the evaporated water. Apparently the main applications of the process have hitherto been to steam-free HCl-rich gases but a recent paper* by REINER VIEWEG discusses design methods for the general case of dilute, steam-containing gases. The absorption is represented on a combined boiling curve and enthalpy-concentration diagram. The acid concentration which can be achieved is derived from a McCabe-Thiele diagram. Conditions in such an absorber using water or dilute acid as absorbent can be calculated on the basis of mass and energy balances. Diameter of the packed column follows from determining the limiting gas velocity. There appears to be little information on the height equivalent to a theoretical plate and DR. VIEWEG points out that the composition and temperature of the exit gas, the acid concentration and temperature of the absorbing liquid all considerably influence this process. It nevertheless represents a simplification of the process of absorbing HCl-containing gas diluted with steam and inert gases.

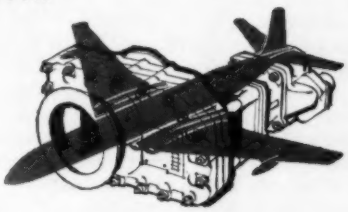
* *Chemische Technik* 1960, No. 9, p. 525.

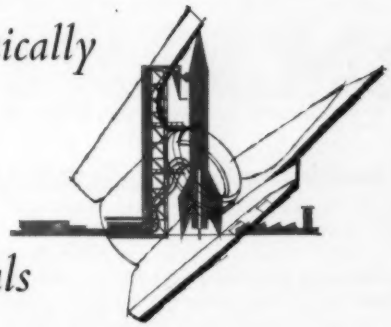
Preventing Waste

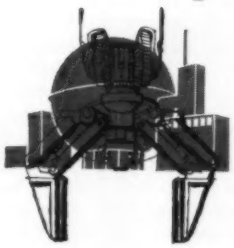
THERE are probably two main aspects to waste prevention. One is to utilise what would otherwise be discarded; the other is to design processes or use materials from the start in such a way as to prevent the production of waste. In a new booklet, D.S.I.R. have

Kanigen *a hard, non-porous corrosion-resistant plate, gives complete uniform coverage even to the most intricately shaped parts. Thickness can be controlled to fine limits. Being chemically deposited Kanigen can be applied to practically all metals in commercial use. It can also be applied to non-conductors such as plastics and ceramics.*









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rather given emphasis to the former type of approach—recalling, though on a much more modest scale, the famous German book on the subject which was published in English translation as "Science and Salvage" (Editor: CLAUS UNGEWITTER: Crosby Lockwood & Son Ltd., London, 1944). Among the examples given in the present publication* is the production of a valuable new animal food by Scottish Malt Distillers Ltd. from the residues of malt whisky distillation. The new product has a high protein value and vitamin B content and makes an important contribution to the diet of poultry and pigs. Some of the distillers' residues had been used as fertilizer but the new application is much more profitable. A further instance is the proposed recovery of magnetic iron oxide from pulverised fuel ash as a feed for blast furnaces. This project is being developed by Warren Spring Laboratory in co-operation with the Central Electricity Generating Board. A pickle liquor recovery process is also mentioned. The British Iron and Steel Research Association has developed to pilot scale an autoxidation process for the recovery of the acid used for pickling steel sheet before tinning. After concentration ferrous sulphate monohydrate crystallises out and is roasted; sulphur dioxide is driven off oxidised to sulphur trioxide and finally recovered as sulphuric acid. None of these, nor any other process, is discussed in detail. The aim of the booklet is evidently to encourage thinking on these problems and to invite contact with the D.S.I.R. Technical Enquiries Section.

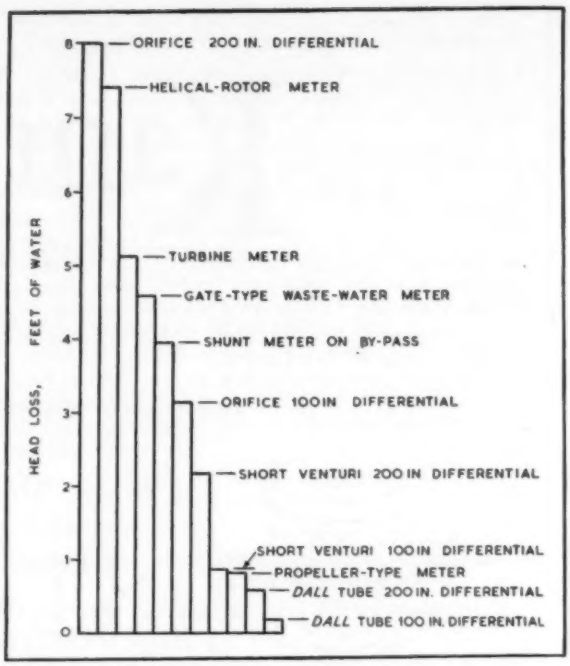
At the Corrosion Exhibition on the other hand† preventing the loss of material is the keynote. Some of the exhibits are of interest for applications in chemical plant.

* "Waste or Wealth" by Clement Brown, Department of Scientific and Industrial Research.

† Corrosion and Metal Finishing Exhibition, Olympia, November 29-December 2, 1960.

What is the Running Cost of a Flowmeter?

IN choosing a flowmeter an important factor is known to be the 'running cost' in terms of usable energy lost due to the meter. There are naturally several other considerations involved in the choice such as the accuracy and flow range required, the type of fluid, effects of any contained impurities, the available locations, the first cost and maintenance cost of the possible types of meter. Furthermore it is not easy to make general comparisons between one type of meter and another even from the point of view of head losses alone, because individual circumstances may so largely affect the issue. However, the diagram above shows some typical loss figures for one size of meter and at one specific flow only which in this case represents a fairly high maximum flow for a pressure



Comparative head losses with various 6 in. meters for a flow of 900 gal. cold water/min.

difference (p.d.) meter. In any other particular case a similar comparison can be made, but using the appropriate data for the types and makes of meter under consideration.

A comparison of the p.d.-type meter with meters of other types is very much affected by the differential heads and maximum flows selected. Also, different designs of turbine, helical and other meters have rather different loss characteristics, other sizes do not necessarily have a proportional loss/flow ratio, and the size of meter is not always the same as that of the main as a whole. Nevertheless, it is possible to examine this problem in general terms and put forward formulae for the financial saving due to the need for reduced pumping power when a lower-loss device is used. In a recent paper* David H. Kent has presented a study which includes a diagram for finding the effect of the choice of differential pressures and meter sizes on the percentage head loss in the case of cold-water flow. It is rounded off with a worked example comparing the capitalised value of the saving using a low head-loss meter against its higher first cost. Perhaps it is natural that the exercise should lead to the conclusion that the low-loss device is justified but in fairness it should be noted that due attention is paid to the existence of cases where this might not be the case. For example, if there is a permanent surplus of head available which would otherwise have to be destroyed by some means, such as the further closing of a valve, then there is no advantage in having a low-loss device.

* *Instrument Engineer*, October, 1960.

Draft Regulations for Construction Sites: Comments Invited

THE Ministry of Labour invite comments on their first-ever drafts of comprehensive regulations governing the safety of workpeople engaged on engineering construction. One set* require the appointment of safety officers, and impose requirements for the protection of persons employed above or below ground, and for fencing all dangerous machinery, whether driven by power or not.

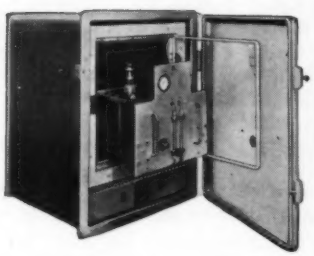
A second set† of draft regulations deal with the construction, use and examination of all lifting appliances, gear and tackle, to ensure the protection of workers who employ them on building operations or works of engineering construction.

* Construction (General Provisions) Regulations H.M.S.O. 9d.
† Construction (Lifting Operations) Regulations H.M.S.O. 1s.

Adsorption Surveyed

THOUGH at first we thought it possible that the Institution of Chemical Engineers had newly re-discovered the existence of surfaces, we understand that it was only by chance that they recently held two symposia on different aspects of this subject. Elsewhere we have referred to a paper at the gathering of the senior body; some ten days later the Graduates and Students Section discussed adsorption in industry. Their programme opened with

Process Analyser



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SCIENTIFIC PYE INSTRUMENTS

a general theoretical survey by J. W. ARMOND of British Oxygen Research and Development Ltd.—which was treated with respect but without discussion—then went on to design and description of hardware. These topics excited much more response from this lively section of the Institution. For drying of gases, S. RUHEMANN of A.E.I.—Birlec suggested that adsorption is economical where the dew-point required is below about 5°C. For dew-points below —20°C it was practically indispensable. There are several possible methods of carrying out drying by adsorption, but for most purposes the dual fixed-bed dryer was proposed as the most economical. MR. RUHEMANN then went on to discuss design of gas dryers in terms of the moisture content of gases, equilibria of adsorbents and their characteristics in respect of mass, heat and momentum transfer rates. In fixed-bed operation the problem is complicated by the transient character of the transfer processes. As in many processes, the basic design problem is that of determining the optimum balance between mass and heat transfer rates and pressure drop. The practical engineering and economic problems are selection of desiccant, choice of cycle period, method of operation (whether manual or automatic), method of regeneration and flow control, and lay-out of plant.

In the following paper J. F. EDWARDS of Union Carbide Ltd. placed emphasis on the newer separation processes which utilise the selective properties of molecular sieves. There are interesting materials and it is impressive to note how quickly they have been introduced for industrial drying and purification of a large variety of gas and liquid streams.

Boiling Heat Transfer in Nuclear Reactors

BECAUSE of rising interest in the boiling water type of nuclear reactor and in the phenomenon of local boiling (which is now considered acceptable) in the pressurised water reactor, increasing attention is being paid among nuclear engineers to heat transfer under these conditions. In an article citing 59 references on the subject, C. S. EMMERSON of the University of Western Ontario, Canada, has reviewed* the current state of knowledge. Tables are presented of proposed formulae for nucleate boiling heat transfer and for burn-out correlations. The burn-out heat flux is taken as the point of transition from nucleate to film boiling—designated as Critical Heat Flux or Departure from Nucleate Boiling (DNB). In the sub-cooled region where the bulk liquid temperature is below the saturation temperature the DNB flux decreases as the pressure increases for the pressure range 500-2000 psia. In the region where the bulk liquid is up to saturation temperature and there is net steam generation, the DNB flux also decreases with increasing pressure over the range 1000 to 3000 psi. There are indications that there is a maximum DNB flux in this case in the vicinity of 1200 psi of magnitude about 20 per cent greater than that observed in the region of 600 and 2000 psi. Outside this range the variation of DNB flux with pressure is not marked.

Channel size and geometry also have an influence on DNB flux. It was originally suspected that the dependence was upon the L/D ratio, the DNB flux decreasing with increasing L/D; but recent tests indicate that the dependence is upon the diameter or equivalent diameter and that the DNB flux decreases as the diameter decreases.

The specific influence of mass velocity on the DNB flux is not very clear. At 2000 psi the DNB flux increases slightly with increasing mass velocity but there seems to be a lower limit of mass velocity below which there is no influence. This lower limit at 2000 psi has been reported as 1.6×10^6 lb/ft²h.

* *Nuclear Engineering*, November, 1960, p. 493.

DIARY

Institution of Chemical Engineers

December 1. *Graduates and Students Section, London Centre.* At Battersea College of Technology, London, S.W.11. "Contracting and design," by N. L. DICKENSON. **6.45 p.m.** Tea 6 p.m. for those ordering in advance.

December 1. *Graduates and Students Section, Manchester Centre.* At Manchester College of Science and Technology. "Reactor Design," by K. G. DENBIGH. **7 p.m.** High tea 6 p.m. for those ordering in advance.

December 6. At the Geological Society, London, W.1. "Study on electro-precipitator performance in relation to particle size distribution, level of collection efficiency and power input," by D. O. HEINRICH. **5.30 p.m.** Tea 5 p.m.

December 7. *Midlands Branch.* At the Midland Hotel, Birmingham. "Noise problems in a large refinery," by M. B. SHIRLEY. **6.30 p.m.**

December 7. *Graduates and Students Section, South Wales Centre.* At Bridgend Technical College. Lecture by J. F. RICHARDSON. **7 p.m.**

December 8. *Graduates and Students Section, Yorkshire Centre.* At the Houldsworth School of Applied Science, Leeds 2. **7 p.m.** Tea 5.15 p.m. for those ordering in advance.

Society for Chemical Industry

December 1. *Corrosion Group.* At Empire Restaurant, Olympia, London, W.14. "The Influence of Water Movement on Corrosion." "Ferrous Materials," by Dr G. BUTLER; "Non-ferrous Metals," by Dr N. V. NOWLAN. **2 p.m.** and **3.45 p.m.**

December 7. *Midlands Branch of Corrosion Group.* At Engineering Centre, Stephenson Place, Birmingham. "Cavitation," by Dr. D. J. GODFREY. **7 p.m.**

December 8. *Chemical Engineering Group.* At University of Bristol Chemical Department. "Some Design Aspects of Gas-cooled Nuclear Power Stations," by R. E. BUCKNELL. **6 p.m.**

December 13. *Chemical Engineering Group.* At 14 Belgrave Square, London, S.W.1. "Mechanical and General Maintenance Problems of the Chemical Industry," by R. H. KEAN. "Electrical Maintenance Problems of the Chemical Industry," by D. MARSHALL. **6 p.m.**

International Events

December 1-3. Thirty-first meeting of the European Federation of Chemical Engineering. Finnish Days of Chemistry 1960 organised by the Kemian Keskuliito-Kemiska Centralforbundent. At Helsinki.

November 30-December 2. Second International Reinforced Plastics Conference. At the Cafe Royal, London. Details from British Plastics Federation, 47-48 Piccadilly, London, W.1.

Advance Notices

March 6, 7, 8, 9, 1961. Oil & Colour Chemists' Association Thirteenth Technical Exhibition. At Royal Horticultural Society's New Hall, London, S.W.1. Enquiries to the General Secretary.

November 8, 9, 10, 1961. The Institution of Electrical Engineers in association with the British National Committee on Non-Destructive Testing. Conference on Non-Destructive Testing in Electrical Engineering. At The Institution. Enquiries to the Secretary.

May 15, 16, 17, 18, 1962. International Rayon and Synthetic Fibres Committee. World Congress for Man-Made Fibres. Enquiries to DR. L. LANDSMAN, 29-31, Rue de Courcelles, Paris, 8.

April, 1962. International Fluid Power Conference to include technical papers and also manufacturer-user discussion sessions. Enquiries to journal "Compressed Air & Hydraulics."

A COST ENGINEERING ASSOCIATION FOR BRITAIN

UNTIL recently there did not exist in Britain a professional body concerned solely with costing. Now, we are happy to announce, this gap has been filled by the formation of a British body, a counterpart of the American Association of Cost Engineers (A.A.C.E.).

In a generalised form, the objects of the newly-formed body are the application of scientific principles and methods to cost estimating, cost control and profitability.

It is intended to provide forums to permit the exchange of experiences in the use of various techniques of cost engineering and, wherever possible, to obtain publication of useful material for the benefit of the engineering fraternity. The promotion of standardisation in terminology and methods will also be an important objective, as will be the co-operation with other organisations having an interest in cost matters.

An important function of the new association, is to be the gathering and dissemination of cost data and the development of improved methods for estimating rapidly the costs and profitability of various ventures.

In the field of capital cost control it is aimed to select and define the various terms used in capital cost estimating. It is intended ultimately to prepare a brief cost code which will form the basis of a method of classifying costs for the purpose of cost control and cost estimating. For the important task of estimating capital costs it is hoped to recommend procedures with the appropriate terminology for their estimation and, very significant, the accumulating of cost data for publication.

Another aim is to publish a cost index manual which will indicate the main application and limitations of construction cost indices. Further aims include the development of methods for estimating and controlling operating costs and for assessing prospective investments.

The officers of the organisation are to hold their inaugural meeting on 12th December. So far the venue has not been fixed but further information may be obtained from any of the following officers.

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British Chemical Engineering
A HEYWOOD PUBLICATION

Plant Operation and the Chemical Engineer

DURING the past twenty years chemical engineering has travelled far along the road to becoming a science rather than an art, and it is now readily accepted that the basic engineering sciences have to be combined in producing plants which are capable of making chemicals available in large quantities, and often with a high degree of purity, at reasonable prices. This is one of the reasons for the growing interest in the so-called optimisation techniques, in which every aspect of a project, excluding questions of æsthetics, but including the profit element, is considered in order to arrive at an optimum design, a process requiring all the items which enter into the cost of a chemical to be expressed in pounds, shillings and pence. A great deal of this work has depended upon the use of high-speed computers.

Among many recent developments in the chemical process industries has been the emergence of chemicals containing tailor-made molecules with properties engineered for a specific use. This new "molecular engineering" has been particularly evident in the production of synthetics devised to replace many of the established constructional materials such as wood, natural rubber and steel; such polymers based upon ethylene, propylene and a number of other basic petrochemicals, spring to mind in this connection. In other fields there is competition with cotton and wool, by synthetic fibres, whose number is increasing rapidly; synthetic detergents have replaced soap in the laundry and in the home. Such examples, which by no means exhaust the fields of these special molecules, emphasise the existence of an expanding field where chemical engineers develop, design and operate the processing equipment required by these many products.

One wonders, however, if the spectacular nature of many of the developments of today does not obscure a few of the most valuable and, at the same time, most inspiring, fields of chemical engineering activity. We refer to what is often regarded as the end-product of chemical engineering activity, the process plant. It is here that we are at one of the truly creative points of chemical engineering achievement; and to underline its significance it is worth recalling that the first successful plant for the manufacture of soda ash was the fourteenth of its kind to be constructed. The attempts to evolve a successful plant covered a period of thirty years with enormous wastage of resources. It cannot be doubted that a greater concentration upon the chemical engineering problems would have led to a great reduction in expense and, moreover, the products of this industry would have been available in large quantities far sooner.

Design is often taken to mean the desk calculations, flow sheets, equipment drawings and sometimes construction is also included, but the true design process should also include the successful operation of plants, and should therefore be a continuing one. The fascination of chemical engineering probably lies as much with the continual improvement of operating plant as it does with the original work of design and development, and there are many cases on record where plant improvements have arisen from a close association of engineers with the operation of plant.

Perhaps the outstanding thing about chemical engineering at the plant is the immense variety of problems with which it confronts the engineer. Many of these are short term in nature and their solution and understanding are a source of daily satisfaction. Other problems may be much more long term in their character, and their solution demands as great a grasp of fundamental knowledge and ability to use it as does much of research, experimental and development work. In short, the plant is to be seen as an arena where the chemical engineer is able to put scientific fundamentals to use in interpreting its day-to-day behaviour, and the current interest in optimising performance techniques emphasises the importance of systematic observation of plant performance. It is a mistake, though, to regard optimisation as something new, because chemical engineers, according to the degree of interest and the time available, have sought to optimise plant performance long before the advent of the computer. The ready availability of calculating machines does, however, provide an infinitely greater scope for the engineer at the plant. He can, for example, by making a number of repeated small changes, and by observing their consequences, find it possible to define the operating grid for plant performance, and determine the optimum conditions of operation without making drastic changes.

A hopeful sign in recent years has been the tendency to transfer the more routine duties of engineers to clerical people and to experienced practical men; this, apart from the use of calculating machines, has also given chemical engineers a great deal more freedom to concentrate on the study of plant operations. The best use of this greater freedom requires a clear understanding of the fact that many plant problems can, in principle at least, be solved by calculations based upon known scientific fundamentals. It is a situation in which the engineer will need to make use of the results of scientific research in the widest sense and, in the case of complex problems, it may be possible to use the plant as its own analogue, a practice which has the advantage of providing measurements on a much larger scale than in research. One benefit of this approach is the detecting of effects likely to be missed under conditions of small-scale work.

As the chemical engineer becomes less and less occupied with the handling of routine data, he should also have greater opportunities for drawing upon the experience accumulated by the operating staff of a plant. They indeed are in much the same category as grandparents of a sick infant; they are familiar with the major and minor details of the unit, with small changes in operation, and with the sequence which these changes follow. Their experience and knowledge may well provide the engineer with valuable pointers in his work of analysing plant operation, and in devising improvements, whether technical or economic. This approach may often mean the difference between success and failure.

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FACTORS IN THE DESIGN OF CONTINUOUS CRYSTALLISERS

Operating variables can be predicted when growth rate data for a system can be expressed in a certain form

by S. H. BRANSOM, Ph.D., A.M.I.Chem.E.

THERE is an abundance of reported work on many aspects of crystal growth in various media, and perhaps the most notable feature in this work is the divergence between the results obtained for any one system under apparently similar conditions. It is well known that a number of factors are important in the operation of the suspended-bed type of continuous crystalliser and also that these factors are inter-related in an almost intractable manner. A number of attempts have been made to rationalise these relationships, in order to distinguish the controlling variables from the many dependent variables. The analyses of this type of crystalliser, presented by MILLER and SAEMAN[1] and SAEMAN,[2] are the most important contributions to this rationalisation. The analyses presented here concern the same process, in which a mass of crystals is suspended in an upward-flowing stream of supersaturated liquor. The system is essentially a liquid-fluidised bed and the flow dynamics are identical with those of liquid-solid fluidisation.

In this process, where crystals grow in a stream of liquid, the effect of the relative velocity between crystal and liquid is important and studies of mass transfer in fluidised beds are therefore relevant to the case. Since, however, there are at least two factors, namely diffusion and a surface reaction, one or both of which may be rate controlling, it is inevitably difficult to generalise rate data for the growth of a variety of crystal systems by means of mass transfer coefficients. It will be shown that when the growth rate data for a given system can be assembled in a particular way, the analysis of the operational details is greatly simplified.

1. The General Conditions of Operation

We consider only the vessel in which crystallisation is taking place. In steady state, crystal nuclei are assumed to enter the vessel at a constant number-rate $dN/dt = G$, and product crystal is drawn off at a constant weight-rate R, called the "rate of make". In steady state the feed of excess solute to the unit is also equal to R. Liquor entering the bottom of the vessel passes upwards through the bed of growing crystals, thereby fluidising them to a suspended bed, and overflows to a recycle pump which returns it to the bottom of the vessel. In the case of a cooling type process a feed of concentrated solution, at a higher temperature than the recycle, is fed into the recycle. The combined flow passes through a cooler so that, emerging at the operating temperature, the liquor is now supersaturated and the excess solute deposits on the crystal mass. In the case of evaporator-crystalliser, the recycle passes through an evaporator where solvent is withdrawn to leave supersaturated solution. The materials lost by evaporation and deposition are replaced by a feed stream, either into the recycle or directly into the crystalliser.

The source of crystal nuclei is debatable; we show below that the supersaturation level should be lower than the metastable limit at which spontaneous nucleation will occur in the crystalliser and, whilst it is considered by some that attrition between crystals produces "chips", others consider that spontaneous nucleation in the cooler or evaporator is the more likely source. We shall not debate this aspect and, whilst any source of nuclei may be expected to yield fine crystals with a definite, average size-distribution, we shall assume a uniform small, finite size (radius r_o) for these nuclei. This assumption is justified by the fluidisation dynamics, since the smallest particles will be swept out of the vessel, to be collected in a fines separator when necessary, and the larger "nuclei" will join an appropriate size group in the suspended bed and will appear to have arisen as true nuclei.

One of the most important operating conditions governs the initial supersaturation and has been noted by MILLER and SAEMAN,[1] by RUMFORD and BAIN[3] and also in this laboratory (work to be published). In order to avoid excessive numbers of very fine particles, the maximum level of supersaturation anywhere in the crystalliser must not exceed the metastable limit at which the rate of spontaneous nucleation becomes measurably large.[4] It has been found, however, that the maximum allowable supersaturation is set at an even lower level by the effect on the "quality" of the product. Thus as the supersaturation approaches this limit, most substances begin to develop friable, irregular crystals containing occlusions of parent liquor. Such crystals

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Symbols Used

a = Specific growth rate.
A = Surface area of crystal per unit volume of suspension.
b = Exponent of r in growth rate equation.
B_1 = Constant term in Equation (18).
B = Constant term in Equation (22).
C = Constant term in Equation (18).
c_f = Concentration of solute in "stock".
c_o = Saturation concentration of solute at temperature of operation.
D = Constant term in Equation (23).
g = Acceleration due to gravity.
G = Number-rate of entry of nuclei.
h = Height above bottom of vessel.
h_o = Total height of suspension.
J = Ratio of product off-take to total weight of suspension.
k = Constant term in Equation (4).
n = Exponent of S in growth rate equation.
$N(r)$ = Number-size distribution function.
N_o = Number of nuclei in first size group.
q = Flow rate of "stock" (volume per unit time).
Q = Total liquor flow (volume per unit time).
r = Equivalent radius of crystal.
r_o = Equivalent radius of nucleus crystal.
r_m = Equivalent radius of largest crystals.
r_{max} = Equivalent radius at maximum in function $W(r)$.
r_{av} = Average equivalent radius.
R = Rate of make (weight of crystal per unit time).
Re′ = Modified Reynolds number.
S = Supersaturation.
S_1 = Supersaturation of entrant liquor.
S_{av} = Average supersaturation.
t = Residence time in crystalliser.
V_o = Superficial velocity of liquor ($V_o = Q/a$).
V_r = Relative velocity between crystal and liquor.
W = Total weight of suspended bed.
$W(r)$ = Weight distribution function.
a = Cross-sectional area of crystalliser.
$\epsilon(r)$ = Void fraction corresponding to crystals of size r.
ϵ_{av} = Average void fraction over the whole bed.
ρ = Density of solid.
ρ_l = Density of liquid.
χ = Constant in Equation (25).
μ = Viscosity of liquor.

exhibit poor mechanical resistance to handling and transport and the occlusions usually lead to caking during storage. At present there is no alternative to actual experiments in order to determine this limit of supersaturation, although it is thought that the effect has something in common with the formation of mists and fogs in supersaturated vapours. In what follows we assume that this level is known and that the maximum desirable supersaturation is S_1 (weight of excess solute per unit volume of entering liquor). The volume flow of liquor, Q, the supersaturation S_1 and the rate of make are related by

$$S_1 \,.\, Q = R$$

In the case of a cooling crystalliser (Fig. 1), a volume flow q of "stock" carrying c_f (weight of solute per unit volume) will release

$$R = q \,.\, (c_f - c_o)$$

of solute where c_o is the saturation level at the working temperature. Then

$$S_1 = q\,\frac{(c_f - c_o)}{Q}$$

Saturated liquor will therefore accumulate at the rate q unless it is withdrawn. All or part of flow q may be withdrawn with the product crystals. In the case of evaporative operation the influx of stock must bring with it sufficient solvent to account for that evaporated off and that withdrawn with the product, unless this latter is recycled after separating the crystals.

Although this type of continuous crystalliser is sometimes referred to as "classifying", it is doubtful whether exact size-classification, resulting in strata of narrow size ranges down the vessel, is ever effected. More commonly there is an almost complete intermixing of all sizes, but, it may be noted, this does not necessarily mean any large degree of back mixing in the liquor flow, as shown by recent experiments in this laboratory (to be published). By appropriate location of the product off-take, however, a reasonable degree of classification can be effected in the final size group in the vessel. Thus the product crystals are effectively only the largest crystals of the suspended mass, although some smaller crystals are inevitably entrained. We shall treat this case as though the product is classified exactly. More commonly the product is withdrawn unclassified and represents the same number fraction of all the size groups present. At the other extreme we examine the case of exact classification in order to discover whether there is any obvious incentive to achieve this condition.

2. The Growth Rate Data

Rates of growth of crystals have been measured in a variety of ways for many substances and under various conditions. Here we shall regard crystals as equivalent spheres of radius r; in other words, we shall measure a convenient half-dimension and use a shape factor $4\pi/3$. The rate of growth will then be measured as dr/dt, which differs from the rate of mass transfer per unit area of crystal only by a factor of density ρ. Thus:

$$dm/dt = \rho \,.\, dr/dt$$

The growth rate depends on the supersaturation of the liquor and also on the velocity of liquor relative to the crystal. The former dependence is generally satisfied by a relationship of the form

$$dr/dt \sim S^n$$

The exponent n is known to be $\simeq 1$ for a number of systems, but we shall retain the generalisation. The dependence of the growth rate on the relative velocity can be expressed in a number of different ways. McCabe and Stevens[5] have shown that the growth rate is given by a function

$$\frac{1}{(dr/dt)_g} = \frac{1}{(dr/dt)_o + \beta V_o} + \frac{1}{(dr/dt)_i}$$

Where subscript g indicates a finite relative velocity, subscript o indicates zero relative velocity and i indicates the limit to which dr/dt approaches with velocity V_o increasing. In the type of process in question, the case of zero velocity does not arise and it is thought that a simpler form of function should be permissible for the process. Studies of liquid-solid fluidised systems have shown[6] that momentum transfer in these systems can be correlated with other variables through a modified Reynolds number Re′ where

$$\mathrm{Re}' = 2r \,.\, \rho_l \,.\, V_r/\mu$$

It was thought to be likely that the same Reynolds number would occur in a mass transfer correlation. Although there is a scarcity of data suitable for analysis, the results of Hixson and Knox[7] for copper and magnesium sulphates are amenable to this type of correlation. Assuming the form

$$dr/dt = a(\mathrm{Re}')^b\, S^n$$

for the complete growth rate equation, the value of n was first found from the values of $dr/dt(S)$ at values of Re′ $\simeq$ constant. It was found that $n = 1$ for both copper and magnesium sulphate. Plotting the assembled data in the form log $[(dr/dt)/S]$ versus log. $(2r \,.\, V_r)$, Figs. 2 and 3

show that $b \simeq 0.65$ for $CuSO_4 . 5H_2O$ and $b \simeq 0.3$ for $MgSO_4H_2O$. It is only necessary to use r and V_r in the analysis, since ρ_l and μ are effectively constant in each series.

In a continuous crystalliser the superficial velocity V_o of liquor (referred to the empty vessel), ρ_l and μ are constant for a given case and although $V_r = V_o/\epsilon$, ϵ varies but little and is proportional to $r^{-\frac{1}{3}}$ and so we can simplify the growth rate equation for a given case to

$$dr/dt = a . r^b . S^n \qquad \ldots . (1)$$

It will be shown (Equation (19)) that the data necessary to establish a, b and n are readily collected in a series of relatively simple experiments.

In two of the three cases we discuss, the mass and number balances can be combined to yield the rate of entry, G, of nuclei. The rate of make, R, is related to the volume flow rate and supersaturation as we have seen. When the product is classified, so that only crystals of size r_m emerge, the number rate of product crystals is equal to the number rate of entry of nuclei. It follows, therefore, that

$$R = \frac{4}{3}\pi\rho G\,(r_m^3 - r_o^3) = S_1 Q = \alpha V_o S_1 \qquad \ldots . (2)$$

where α is the cross-sectional area of the vessel. In many cases r_o will be negligible compared with r_m and we may neglect r_o^3 above. When the product crystals are unclassified the number rate of emergence must also be $dN/dt = G$, but since all size groups are present, there is no simple combination which will permit G to be calculated.

3. Case I. Mixed Suspension. Classified Product

We consider first the case where all size groups in the suspended bed are mixed except the largest, of radius r_m, which are just not supported by the liquid stream and therefore sediment to become the product. We further assume that all crystals traverse all regions of the classifier in a cycle whose period will be short compared with the total residence time required to grow from r_o to r_m. Thus we can consider the growth of each crystal to be governed by an average supersaturation $S_{av} < S_1$. It must be noted that since crystals must pass through regions where the supersaturation is S_1, the value S_1 may not exceed the maximum supersaturation fixed by the desired quality of the product. In order to calculate S_{av}, we require the distribution $S = S(h)$ where height h of suspension is measured from the bottom of the vessel.

(i) Distribution of Supersaturation

We consider the horizontal slice of suspension, thickness dh at a height h above the bottom of the vessel (Fig. 4). Since the suspension is mixed, we may regard the surface area A of crystal per unit volume of suspension as constant throughout the entire suspension.

The volume flow rate of liquor is αV_o and hence the rate of desupersaturation in this slice is given by

$$\frac{-d\,(\alpha V_o S)}{dh} . \delta h = A . \alpha\,\delta h . \frac{dr_{av}}{dt} \qquad \ldots . (3)$$

where dr_{av}/dt is the average growth rate of all sizes of crystals at the level h in the vessel.

$$dr_{av}/dt = \frac{\int_{r_o}^{r_m} ar^b\, S^n(h) . dr}{\int_{r_o}^{r_m} dr}$$

$$= \frac{a . r_m^b . S^n(h)}{b+1} \quad \text{(neglecting } r_o\text{)}$$

All the factors except $S(h)$ are constant and we can abbreviate the average growth rate to

$$dr_{av}/dt = k\,S^n(h)$$

Substituting this value in Equation (3), we have for $n \neq 1$

$$-V_o . \frac{dS(h)}{dh} = A . kS^n(h)$$

or

$$\frac{1}{1-n} . S^{1-n} = \frac{A . k}{V_o} . (h_o - h) \qquad \ldots . (4)$$

with the boundary condition $h = 0$, $S = S_1$. In case $n = 1$ we obtain a logarithmic distribution

$$\log (S_1/S) = \frac{A . k}{V_o} . h.$$

RUMFORD and BAIN[3] concluded that a logarithmic distribution of supersaturation is the most rational assumption, but it will only arise in case $n = 1$, although it may also be closely approached when $n \simeq 1$. The present author and a co-worker developed a technique by which the distribution of supersaturation is fairly readily measured for certain types of system and one system examined obeyed Equation (4) with $n = 0.4$ (to be published).

(ii) The Average Supersaturation

It will be clear that we cannot calculate a correct time-average supersaturation unless we know the average period

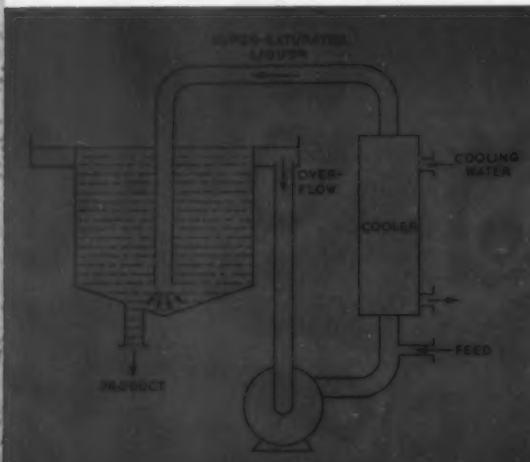

Fig. 1. Schematic diagram of continuous, cooling type crystalliser. Details such as the feed entry, the method of product removal and cooler design may vary considerably between particular cases.

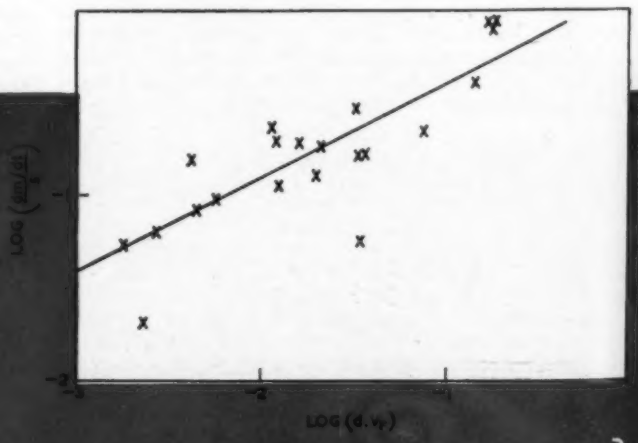

Fig. 2. The plot of $\log\left(\frac{dm/dt}{S}\right)$ versus $\log (d . V_r)$ for $CuSO_4 . 5H_2O$ from the data of Hixson and Knox.[1]

of cycle of the suspension. On the other hand, we can make the useful approximation

$$S_{av} = \frac{\int_o^{h_o} S(h)\, dh}{\int_o^{h} dh}$$

and obtain the distribution average. Two cases arise:

$$\text{(a)} \quad n \neq 1 \quad S_{av} = \left(\frac{1-n}{2-n}\right) . S_1 \qquad \ldots . (6)$$

$$\text{and (b)} \quad n = 1 \quad S_{av} = \frac{V_o S_1}{h_o Ak}\left[1 - e^{\left(\frac{-Ak}{V_o} \cdot h_o\right)}\right] \qquad \ldots . (7)$$

In practice, where the liquor overflowing will carry a residual supersaturation of the order of 5-10 per cent of S_1, we may usefully approximate Equation (7) to

$$S_{av} \simeq 0.23\, S_1 \qquad \ldots . (7a)$$

It will be seen from Equation (6) that values of n, $1 < n < 2$ would appear to be prohibited, since S_{av} must be positive.

(iii) Residence Time

The residence time of crystals has an important bearing on the hold-up and hence on the size of the vessel which contains the suspension. The time required to grow a crystal from r_o to r_m is given by

$$\frac{dr}{dt} = a\, r^b\, S_{av}^n$$

which integrates to give

$$t = \frac{1}{a\, .\, S_1^n}\left(\frac{2-n}{1-n}\right)^n \cdot \frac{1}{(1-b)} \cdot (r_m^{1-b} - r_o^{1-b}) \qquad \ldots . (8)$$

The residence time, and hence the size of the vessel, will be markedly dependent on r_o if $b > 1$, but relatively independent (from the rate of growth point of view) if $b < 1$. If the values of b which were derived from the data of HIXSON and KNOX[3] are at all representative, the term in r_o may be neglected. We see below that the size r_o makes an important contribution to the vessel size by reason of its fluidisation characteristics (vi).

(iv) The Total Weight of Suspended Crystals

The total weight of crystals in the vessel must be such that the rate of growth, integrated over the total surface, is equal to the rate of make. On the other hand, we may sum the weight of all size groups in the suspension and since the numbers in those groups are related to the rate of make, the calculation yields the required result. The total weight W is given by

$$W = \frac{4}{3}\pi\rho \sum_{r_o}^{r_m} r^3\, N(r)\delta r$$

where $N(r)\delta r$ is the number of crystals whose sizes lie between r and $r + \delta r$. The number in such a group is the product of the rate at which crystals enter (or leave) the group and the time taken to grow through the group, i.e., the time to grow by δr. Thus

$$N(r)\delta r = G\, .\, \delta r\, .\, /dr/dt \qquad \ldots . (9)$$
$$= G\, .\, \delta r/a\, .\, r^b\, S_{av}^n$$

Making δr differentially small, we write

$$W = \frac{4\pi\rho G}{a\, S_{av}^n} \int_{r_o}^{r_m} r^{3-b}\, dr$$

Integrating and substituting for G from Equation (2) we obtain

$$W = \frac{\alpha\, V_o\, S_1}{a\, S_{av}^n\, (4-b)} \cdot (r_m^{1-b} - r_o^{1-b}) \qquad \ldots . (10)$$

where S_{av}^n may conform to Equations (6), (7) or (7a). The ratio of hold-up to throughput is thus

$$W/R = \frac{r_m^{1-b}}{a\, S_{av}^n\, (4-b)} \qquad \text{(neglecting } r_o\text{)} \qquad \ldots . (11)$$

We show below that V_o is fixed by the fluidisation characteristics of crystals of size r_m. Hence, for the purpose of scale-up, Equation (10) shows that the cross-sectional area of the vessel must change in proportion to W. The supersaturation decay $S(h)$ must always be the same function for the same system and it is not valid to accommodate a greater mass of suspended crystal by increasing h_o. To do so would mean that a large fraction of the bed would occupy a region of low supersaturation and the average S_{av} would fall unduly. It may be noted in passing that Equation (10) requires $b < 1$, since otherwise W would vary inversely with r_m which is unreasonable.

(v) The Dimensions of the Crystalliser

The dimensions of the bed of suspended crystals of known weight and size distribution are fixed by the fluidisation characteristics of the bed. When the rate of make R and the maximum tolerable supersaturation S_1 are known, the volume flow of liquor $Q = \alpha V_o$ is fixed. Since we require that crystals of size r_m shall separate from the remainder of the suspended bed, the superficial velocity V_o must be just

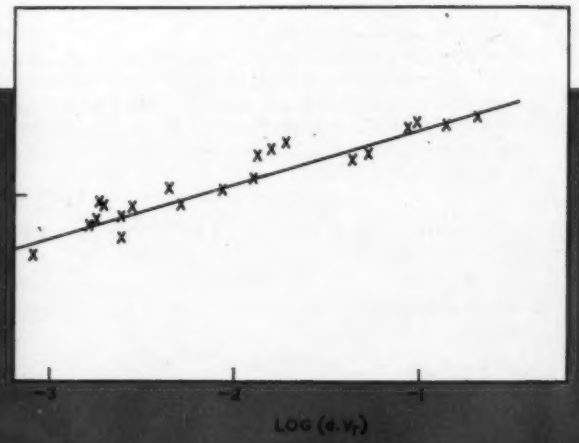

Fig. 3. The Plot of log $\left(\frac{dm/dt}{S}\right)$ versus log (D . V$_t$) for $MgSO_4.7H_2O$ from the data of Hixson and Knox.[3]

Fig. 4. A horizontal slice of suspension of thickness δh *situated at height* h *from the (plane) bottom of the suspension.*

less than the minimum superficial velocity necessary to fluidise particles of this size. It has been found from studies of liquid-solid fluidised systems[6] that the relevant variables are correlated by the equation

$$\frac{2}{3}\left[g \cdot \rho \frac{(\rho - \rho_l)}{3}\right]^{\frac{1}{3}} \cdot \frac{(2r \cdot \varepsilon)^{3/2}}{(1-\varepsilon)\mu} = 2.63 \left(\frac{4\, V_o\, r\, \rho_l}{3(1-\varepsilon)\mu}\right)^{0.76} \quad \ldots.(12)$$

for the range $2 < Re' < 250$ where the group in parentheses on the right-hand side of Equation (12) is Re'. It was also found that a reasonable approximation to the minimum value of V_o (the minimum fluidising velocity) is given by setting $\epsilon = 0.4$. This value for the minimum void fraction ϵ is valid in fact only for isometric and near-isometric particles. When irregular (plate-like, needle-like, etc.) particles are employed, the minimum value of ϵ is nearer to 0.5. Since we have the values of all other factors in Equation (12), the selected value of $r = r_m$ and $\epsilon = 0.4$ (or 0.5) will yield the maximum value of V_o which will allow particles r_m to settle out. The value used in practice will be slightly smaller than that calculated. The cross-sectional area a of the vessel then follows directly from

$$aV_o = Q$$

The height h_o occupied by the whole suspended bed can best be calculated through the average void fraction ϵ_{av} for the whole system. This may be done in two ways. First, we define an average particle radius r_{av} by

$$W = N_{(tot)} \frac{4}{3} \pi \rho r_{av}^3$$

where $N_{(tot)}$ is the total number of suspended crystals in steady state.

$$N_{(tot)} = G \times \text{total residence time}$$

$$= \frac{3\, a\, V_o\, S_1}{4\, \pi\, \rho\, a\, S_{av}^n \cdot (1-b) \cdot r_m^{2+b}}$$

Hence

$$W = \frac{a\, V_o\, S_1\, r_m^{1-b}}{a\, S_{av}^n\, (4-b)} = \frac{a\, V_o\, S_1\, r_{av}^3}{a\, S_{av}^n \cdot (1-b) \cdot r_m^{2+b}}$$

or

$$r_{av}^3 = \left(\frac{1-b}{4-b}\right) r_m^3$$

Introducing r_{av} into Equation (12) together with V_o we calculate (in principle) the average void fraction ϵ_{av} and hence h_o from

$$\frac{W}{\rho} = (1 - \epsilon_{av})\, a\, h_o \quad \ldots.(13)$$

Equation (12), however, does not allow a simple, explicit calculation of ϵ_{av} (there are alternative equations[6]) and ϵ_{av} may be calculated more simply, provided that the system meets certain requirements. It is the case for many common crystal-liquor systems that the sedimentation of the crystals conforms with the intermediate settling law. When this is so it is readily shown that, when the system is fluidised in a liquid having a given superficial velocity

$$\epsilon_{av}(r) = \text{const}/r^{\frac{1}{3}}$$

$$\epsilon_{av} = \frac{\int_{r_o}^{r_m} \epsilon(r)\, dr}{\int_{r_o}^{r_m} dr}$$

$$= \frac{3}{2}\, \epsilon\, (r_m) \qquad \text{(neglecting } r_o\text{)}$$

Thus when we can set $\epsilon(r_m) = 0.4$, we have $\epsilon_{av} = 0.6$ and in particular

$$W/\rho = 0.4\, a\, h_o$$

or

$$h_o = \frac{2.5\, V_o\, S_1\, r_m^{1-b}}{a\, S_{av}^n\, \rho\, (4-b)} \quad \ldots.(14)$$

(vi) The Size Range r_o to r_m

It is not entirely satisfactory to neglect r_o in calculating Equation (14) above, since the smaller the particle size the closer $\epsilon(r)$ approaches to unity and when $\epsilon(r) \longrightarrow 1$, $a\, h_o \longrightarrow \infty$. The most important factor affecting the depth of the crystalliser in practice therefore will be the void fraction corresponding to the "nuclei". According to Equation (12), the relationship between r and ϵ in a given system can be written

$$r = \text{const.} \frac{(1-\varepsilon)^{\frac{1}{3}}}{\varepsilon^2} \quad \ldots.(15)$$

(We have used the simpler function to derive Equation (14) because the integration of Equation (15) is cumbersome and the simpler function yields effectively the same solution.) The form of $(1-\epsilon)^{\frac{1}{3}}/\epsilon^2$ is illustrated in Fig. 5. In practice the smallest crystals tend to elutriate from the bulk of mixed suspension and, if they are to be retained, $\epsilon(r_o)$ may account for a large proportion of the total depth of the crystalliser. When $\epsilon(r_o) \simeq 0.98$ (each crystal of r_o is surrounded by fifty times its own volume of liquor) and $\epsilon(r_m) = 0.4$ we find from Fig. 5 that $r_m/r_o \simeq 18$. When $\epsilon(r_o) \simeq 0.95$ (each crystal r_o in twenty times its own volume), $r_m/r_o \simeq 10.5$. It becomes evident, therefore, that unless a large proportion of the vessel and consequently a large volume of liquor are available for the retention of fine crystals, the maximum range of the size increase to be expected for a classified product will be about tenfold. The effect can be overcome by providing the crystalliser with an upper extension having a larger cross-section than the main vessel. Decreasing the effective superficial velocity in this way decreases $\epsilon(r_o)$. Equation (12) shows that for a given value of $\epsilon(r_o)$, $r_o \sim V_o^{\frac{1}{3}}$ and hence $\sim 1/a^{\frac{1}{3}}$ when $aV_o =$ const. Hence the size of crystal nuclei retained ($aV_o =$ const.) is inversely proportional to the radius of cross-section.

Since the remarks made in this section apply equally to the analyses which follow, we shall not repeat them in connection with those cases.

4. Case 2. Mixed Suspension. Non-classified Product

The method of operation most frequently encountered in practice yields a product which represents the same fraction of crystals from every size group in the mixed suspension. The fraction of the bed withdrawn in unit time is determined by the ratio of the volume of slurry withdrawn in unit time to the total volume of suspension. The weight of crystals in the slurry drawn off in unit time is equal to the rate of make R. It will be shown that the loss of crystals from all size groups has a marked effect on the size distribution in the suspension and, since the product is not classified, the size r_m has no real meaning other than that size beyond which there are practically no crystals present.

(i) Size Distribution

The size distribution arising in this case is exactly similar to that discussed by BRANSOM, DUNNING and MILLARD.[5] In the present case, however, we are still assuming a constant rate of entry $dN/dt = G$ of nuclei of size r_o and we do not consider spontaneous nucleation. The number rate of loss of crystals from any size group r to $r + \delta r$ is

$$-dN(r)/dt = J \cdot N(r) \quad \ldots.(16)$$

where J is the ratio of the volume of slurry withdrawn in unit time to the total volume of suspension, i.e.:

$$J = R/W$$

At a time $t(r)$ after the entry at size r_o the number of crystals remaining in this group is given by

$$N(r) = N_o \cdot e^{-J \cdot t(r)}$$

where $t(r)$ is the time taken to grow from r_o to r. We define N_o as the number of nuclei entering in the time to grow from r_o to $r_o + \delta r$. Thus:

$$N_o = \frac{G \,.\, \delta r}{dr/dt}$$
$$= \frac{G \,.\, \delta r}{a \,.\, r_o{}^b \,.\, S_{av}{}^n}$$

Further, since

$$t(r) = \frac{r^{1-b}}{a \,.\, S_{av}{}^n \,.\, (1-b)} \quad \text{(neglecting } r_o{}^{1-b}\text{)}$$

$$N(r) = \frac{G \,.\, \delta r}{a \,.\, r_o{}^b \,.\, S_{av}{}^n} \,.\, exp\left[\frac{-J \,.\, r^{1-b}}{a \,.\, S_{av}{}^n \,.\, (1-b)}\right]$$

$$\text{or } \log N(r) = \log\left(\frac{\text{const.}}{a \,.\, S_{av}{}^n}\right) - \left[\frac{J \,.\, r^{1-b}}{a \,.\, S_{av}{}^n \,.\, (1-b)}\right] \quad \ldots . (17)$$

This form of number-size distribution renders formal analyses of the other operating conditions practically intractable but, as we show below, it also provides an alternative to the formal methods.

(ii) Weight-size Distribution

The weight-size distribution $W(r)\delta r$ is of more practical importance than the number distribution $N(r)\delta r$ and it is readily calculated from the weight of crystal $W(r)\delta r$ in the size group r to $r + \delta r$.

$$W(r)\delta r = \frac{4}{3}\pi\rho r^3 N(r)\delta r$$
$$= \frac{4\pi\rho G r^3 \delta r}{3 \,.\, a \,.\, r_o{}^b \,.\, S_{av}{}^n} exp\left[\frac{-J r^{1-b}}{a\, S_{av}{}^n\, (1-b)}\right]$$

which we may abbreviate to

$$W(r)\delta r = B_1 \,.\, r^2 \delta r \, exp\,(-C\, r^{1-b}) \quad \ldots . (18)$$

The accumulative weight distribution, i.e., the weight fraction of the whole suspension corresponding to crystals of radius $\leq r$, is given by integrating Equation (18) between the limits r_o and r. The form of the function $W(r)$ is more interesting, however, and its shape is illustrated in Fig. 6, where the function has been evaluated with $\delta r = 1$.

The units of r in the figure are arbitrary, but they are the same for each curve. Whilst the same general shape is preserved, the position of the size range r_1 to r_2 which accounts for say 50 per cent of the total weight and also the position of r_{max}, corresponding to the maximum in

$$W(r) = r^3 \, exp(-C \,.\, r^{1-b})$$

both vary considerably with b and C. For example, if we take $C = 1$ in curve A, instead of $C = 0.1$ as in the figure, r_{max} occurs at 3 instead of 30. On the other hand, the ratio r_2/r_1 is of the order of 2-3 over a wide range of values of b and C.

The most important result which can be derived from the function $W(r)$ is the position of r_{max}. This is readily shown to be given by

$$r_{max} = [3/C(1-b)]^{1/(1-b)}$$
$$= \left[\frac{3 \,.\, a \,.\, S_{av}{}^n}{J}\right]^{1/(1-b)} \quad \ldots . (19)$$

It is evident that a set of experiments in which r_{max} is measured as a function of S_{av} and J will yield the growth rate data through Equation (19).

(iii) Average Supersaturation

The average effective supersaturation S_{av} is derived in the same way as for Case 1 and is identical except that the surface area of crystal per unit volume of suspension is different. This has no effect on the final relationships between S_1 and S_{av} in cases $n \neq 1$ and $n = 1$.

(iv) Total Weight of Suspension

To attempt to calculate the total weight of suspended crystal by the formal method of Case 1 leads to a practically intractable result. Briefly, employing the simplification $b = 0$, $dr/dt = a \,.\, S_{av}{}^n$, we derive

$$W = \frac{4\pi\rho G \,.\, C^4}{3\, a\, S_{av}{}^n}\left[6 - e^{-C \,.\, r} \,.\, f_1\,(C \,.\, r)\right]$$

where $f_1(C \,.\, r) = 6 + 6C \,.\, r + 3(C \,.\, r)^2 + (C \,.\, r)^3$

and r is equivalent to r_m of Case 1. Even when G is eliminated by the normalisation

$$\int_{r_o}^{r_m} 4\pi\rho G \,.\, r^2 \, exp\,(-\,C \,.\, r)\, dr = \alpha\, V_o\, S_1$$

the result is too cumbersome to be of any use.

Equation (19) can be rearranged to

$$r_{max}{}^{1-b} = \frac{3 \,.\, a \,.\, S_{av}{}^n \,.\, W}{R}$$

or

$$W = \frac{\alpha\, V_o \,.\, S_1}{3 \,.\, a \,.\, S_{av}{}^n} \,.\, r_{max}{}^{1-b} \quad \ldots . (20)$$

and hence

$$\frac{W}{R} = \frac{r_{max}{}^{1-b}}{3 \,.\, a \,.\, S_{av}{}^n}$$

It will be seen that these results are formally similar to Equations (10) and (11) when r_o is neglected in Case 1.

(v) Dimensions of the Crystalliser

The superficial velocity V_o of the liquor is determined in principle as before by the maximum size of particle desired. In practice, r_m will not exceed r_{max} by too great a factor (say $r_m = 2 \times r_{max}$) and V_o can be calculated through Equation (12) with $\epsilon = 0.4$ and the appropriate value of the radius r. Once again α is determined when $R = \alpha V_o \,.\, S_1$, S_1 and V_o have been fixed. It is readily shown as in sect. 3 (v) that $\epsilon_{av} \simeq 0.6$ and we have therefore

$$W/\rho = (1 - \epsilon_{av})\alpha h_o$$

and substituting from Equation (20) we obtain

$$h_o = \frac{2.5\, V_o\, S_1}{3\, a \,.\, S_{av}{}^n\, \rho} \,.\, r_{max}{}^{1-b} \quad \ldots . (21)$$

which may be compared with Equation (14). The remarks concerning the effect of r_o on h_o and the range r_o to r_m (in the present case r_o to r_{max}) also apply to the present case.

5. Case 3. Exact Classification

The case in which exact size-classification occurs throughout the whole suspended bed is undoubtedly hypothetical. It is worthwhile to compare the corresponding results with the foregoing cases, since it has been argued[1] that a classified suspension leads to a poorer quality in the crystal product than does a mixed bed at the same rate of make in the same equipment.

We assume once more the steady state in which nuclei of size r_o enter at the constant rate $dN/dt = G$ and excess solute enters in the liquor stream so that $\alpha V_o \,.\, S_1 = R$. The analysis is similar to Case 1, except that we cannot treat all crystals as growing under the influence of a constant average supersaturation. When the suspension is classified, the smallest crystals grow in a region of low supersaturation and vice versa. Since, however, the analytical procedure is the same, we quote only the relevant results.

The size and supersaturation distributions combine to give

$$\frac{dS}{dr} = \frac{4\pi\rho G \,.\, r^2}{\alpha\, V_o}$$

or

$$S(r) = B \,.\, r^3 \quad \ldots . (22)$$

where

$$B = \frac{4\pi\rho G}{3\alpha\, V_o} = \frac{S_1}{r_m{}^3} \quad \text{(neglecting } r_o{}^3\text{)}$$

The size distribution $r(h)$ in the crystalliser is found to be

$$r^{4-b-3n} = (h_o - h)/D \quad \ldots . (23)$$

where

$$D = \frac{0.4\, a\, \rho\, (4 - b - 3n)}{V_o \,.\, S_1{}^{1-n} \,.\, r_m{}^{3n-3}}$$

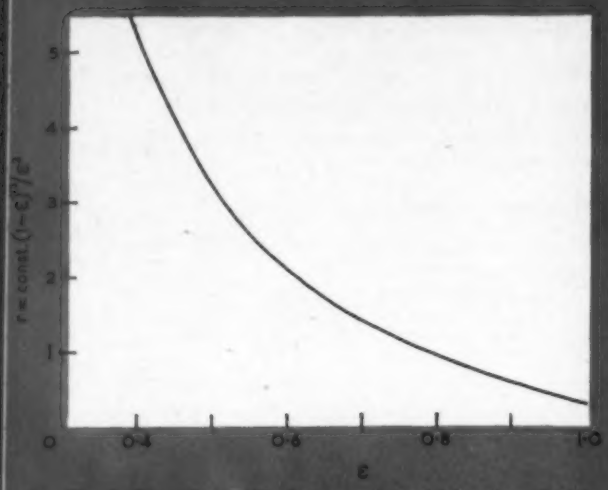

Fig. 5. The relationship between the void fraction of a suspended bed and the radius of (monodisperse) particles is illustrated by the function const: $(1-\epsilon)^3/\epsilon^3$.

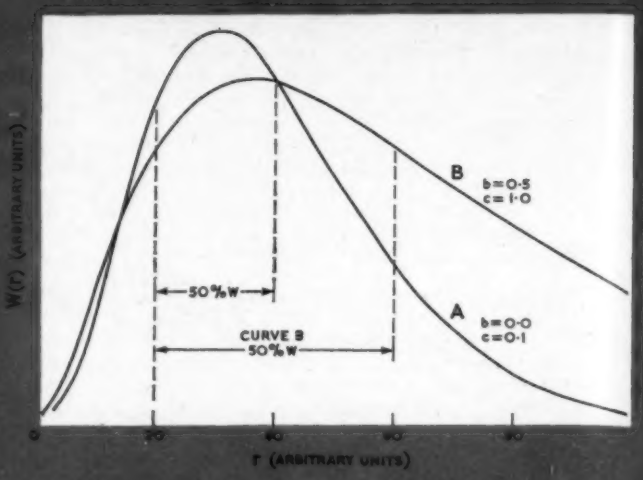

Fig. 6. Curves of the theoretical size distribution function (W(r) versus r) for the product of completely mixed continuous crystallisation.

Since $r = r_m$ when $h = 0$, we obtain directly

$$h_o = \frac{2.5\ V_o\ r_m^{1-b}}{S_1^{n-1}\ a\ \rho\ (4-b-3n)} \qquad \ldots.(24)$$

which is identical with the value given by W, ϵ_{av} and normalising through the total surface area as before.

The supersaturation distribution in the classifier $S(h)$ is found to be

$$S(h) = \frac{S_1}{h_o^{\chi}}\,(h_o - h)^{\chi} \qquad \ldots.(25)$$

where $\chi = 3/(4-b-3n)$. It is evident that $S(h)$ cannot be logarithmic, since this would require $\chi - 1 = -1$, which is not possible. The total weight of suspension is given by

$$W = \frac{\alpha\ V_o\ S_1^{1-n} r_m^{1-b}}{a(4-b-3n)} \qquad \ldots.(26)$$

and hence

$$\frac{W}{R} = \frac{r_m^{1-b}}{a\ .\ S_1^{n}\ .\ (4-b-3n)} \text{ (neglecting } r_o^{1-b}) \qquad \ldots.(27)$$

These results may be compared with the corresponding equations for the foregoing cases.

The minimum fluidising velocity V_o and hence the cross-sectional area of the vessel are fixed as before from the values of r_m and the rate of make $R = \alpha V_o S_1$. The remarks concerning the effect of r_o on h_o and the ratio r_m/r_o apply also to this case.

Conclusions

When the rate of growth of crystals can be expressed in the form

$$dr/dt = a\ .\ r^b\ .\ S^n$$

most of the important operating details of a continuous crystalliser can be predicted. The necessary data can be collected most simply from experiments designed to meet the conditions assumed in Case 2. The limiting value of S_1, the maximum allowable feed supersaturation which accords with the required quality, can also be determined in the same experiments.

The linear, superficial velocity of the liquor stream, based on the volume flow through the empty vessel, is determined by the dynamics of fluidisation of the largest crystals desirable in the product. In turn the superficial velocity V_o and the volume flow rate of the entrant liquor determine the cross-sectional area of the vessel. The equations for the hold-up of solids in the crystalliser show that any change of scale should be effected by changing the diameter of the vessel and not by altering the height of the suspended bed.

Comparing the equations for W and h_o for the cases considered

Case 1: $W = \dfrac{\alpha\ V_o\ S_1\ r_m^{1-b}}{a\ S_{av}^{n}\ (4-b)}$ $\qquad h_o = \dfrac{2.5\ V_o\ S_1\ r_m^{1-b}}{\rho\ a\ S_{av}^{n}\ (4-b)}$

Case 2: $W = \dfrac{\alpha\ V_o\ S_1\ r_{max}^{1-b}}{a\ S^{n}\ 3}$ $\qquad h_o = \dfrac{2.5\ V_o\ S_1\ r_{max}^{1-b}}{\rho\ a\ S_{av}^{n}\ 3}$

Case 3: $W = \dfrac{\alpha\ V_o\ S_1\ r_m^{1-b}}{a\ S_1^{n}\ (4-b-3n)}$ $\qquad h_o = \dfrac{2.5\ V_o\ S_1\ r_m^{1-b}}{\rho a S_1^{n}(4-b-3n)}$

we note that $r_{max} < r_m$ (for the same values of all other factors) and hence the hold-up in Case 2 is likely to be the smallest. On the other hand, S_1^n appears in the denominator for Case 3 and, since $S_{av} \simeq 0.25\ S_1$ ($n \simeq 1$), this may offset the effect of $r_{max} < r_m$ for Case 3. The balance is restored, however, by the presence of $-3n$ in the denominator in Case 3, especially if $b \simeq 0$. There would seem to be no *a priori* case therefore therefore for exact size-classification in the crystalliser on the grounds of economy of vessel size and when an especially narrow size range is required in the product, Case 1 should yield the desired effect.

Although we have not considered the case of back-mixing in the liquor stream, we may conclude, qualitatively, that it would allow a somewhat higher value of the feed supersaturation S_1, but would certainly change the fluidisation characteristics of the suspended bed. Back-mixing would necessitate an increase in the velocity V_o required to fluidise crystals of size r_m and an increase in the average void fraction ϵ_{av} would follow. Thus h_o would increase and one would require a larger vessel unless the process could accept larger nucleus crystals and the proportion of "fines" carried in the overflow could also be tolerated.

REFERENCES
[1] Miller, P., and Saeman, W. C., *Chem. Eng. Prog.*, 1947, **43**, 667.
[2] Saeman, W. C., *A.I.Ch.E. Journal*, 1956, **2**, 107.
[3] Rumford, F., and Bain, J., *Trans. Inst. Chem. Engrs.*, 1960, **38**, 10.
[4] Bransom, S. H., and Dunning, W. J., *Disc. Faraday Soc.*, 1949, **5**, 96.
[5] McCabe, W. L., and Stevens, R. P., *Chem. Eng. Prog.*, 1951, **47**, 168.
[6] Bransom, S., and Pendse, S. To be published.
[7] Hixson, S. W., and Knox, K. L., *Ind. Eng. Chem.*, 1951, **43**, 2144.
[8] Bransom, S. H., Dunning, W. J., and Millard, B., *Disc. Faraday Soc.*, 1949, **5**, 83.

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THE REACTOR UNIT CONCEPT IN PROCESS DESIGN

A rigorous method of reactor design takes account of reaction kinetics, and mass transfer ratio of reactants and products

by G. NARSIMHAN, Ph.D., and L. K. DORAISWAMY, Ph.D.*

Introduction

ONE of the important variables required to be computed in the design of a catalytic reactor is the weight of catalyst necessary for a given duty. The computation of this variable may be accomplished by the Hougen-Watson approach using the method of successive integrations for non-adiabatic, non-isothermal reactors and simpler procedures for adiabatic or isothermal reactors. Many methods have also been developed for predicting temperature and conversion profiles in non-adiabatic, non-isothermal reactors, leading to a more rational computation of the catalyst weight required.

The use of these generalised procedures requires a knowledge of the rate equation for the reaction under consideration, and such a rate equation may not always be available. Further, economic considerations may point to the use of a feed velocity at which mass transfer effects cannot be neglected. Indeed, this may quite often be the case as is apparent from the fact that, for a given catalyst weight, an increase in feed velocity results in a corresponding increase in pressure drop leading to a rise in operating cost which more than compensates the attendant decrease in reactor cost due to a decrease in reactor diameter.

It may thus be seen that an approach based on a simultaneous but independent evaluation of the kinetic and mass transfer effects, without requiring a rate equation, would be of considerable use in reactor design. In this context, the height of a reactor unit concept (*HRU*), first introduced by Lampichler[4] and later elaborated by Hurt,[5] can form the basis for a rigorous development. In the procedure proposed by Hurt, the mass transfer effect of the reactants, HTU_1, was separately estimated, but that of the product, HTU_2, was combined with the kinetic term to give a loosely defined height of a catalytic unit, *HCU*. Further, the definition of *HCU* was restricted to a first-order surface reaction. The purpose of the present paper is to offer a rigorous procedure wherein the limitations inherent in Hurt's development are eliminated and the kinetic term as well as the mass transfer terms for both reactants and products are separately defined and evaluated.

Theoretical Development

Let us consider the simple chemical reaction

$$A + B \rightleftarrows C \qquad \ldots . (a)$$

Symbols Used

a = surface area of catalyst per unit weight;
D = binary gaseous diffusivity;
D_m = mean effective diffusivity of a component in a mixture of more than two components;
D_p = diameter of catalyst pellet;
E = contact efficiency of catalyst;
F = feed rate (mols per unit time);
G = mass velocity of fluid in the reactor expressed as mols per unit time per unit cross-section;
j_d = mass transfer factor defined by Equation (8);
k_g = mass transfer coefficient;
M_m = mean molecular weight;
m = order of the overall process considered as one step;
n = order of the surface chemical reaction;
p = partial pressure in the fluid bulk;
p_i = partial pressure at the fluid-catalyst interface;
p° = equilibrium partial pressure in the fluid bulk;
p_i° = equilibrium partial pressure at the fluid-catalyst interface;
p_i^E = partial pressure actually existing at the fluid-catalyst interface, allowing for the contact efficiency E;
p^1 = partial pressure at the inlet;
p° = partial pressure at the outlet;
p_t = pressure term of Equation (8);
r = rate of surface chemical reaction (mols per unit time per unit catalyst weight);
W = weight of catalyst;
x = conversion;
z = bed height; and
z_e = equivalent film thickness.

Greek letters

ρ = density of fluid;
ρ_m = mean density of fluid;
ρ_B = bulk density of catalyst;
μ = viscosity of fluid; and
μ_m = mean viscosity of fluid.

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TABLE I—Experimental and Computed Data for Catalytic Oxidation of SO_2 over Pt Catalyst

Z (ft)	x (mol SO_2 converted mol SO_2 feed)	COMPOSITION (partial pressure in atm)				W/F lb catalyst/ mol SO_2 feed/ hr	$r \times 10^3$ mol/hr/ lb cat.	$(p-p_i)SO_2$ $\times 10^3$ atm	p_iSO_2 atm	$(p_i^E-p)SO_2$ $\times 10^3$ atm	$(p_i^ESO_2)$ atm	$(p_i^ESO_2)$ atm
		N_2	O_2	SO_2	SO_3							
1	2	3	4	5	6	7	8	9	10	11	12	13
0.075	0.228	0.7450	0.1900	0.0506	0.0149	6.65	26.4	2.540	0.0481	2.400	0.0173	0.0477
0.100	0.270	0.7470	0.1890	0.0478	0.0178	8.72	20.7	1,980	0.0458	1,882	0.0197	0.0443
0.125	0.310	0.7460	0.1878	0.0454	0.0204	10.95	14.0	1,350	0.0441	1,273	0.0217	0.0435
0.150	0.337	0.7470	0.1870	0.0435	0.0222	13.10	8.4	0.807	0.0427	0.764	0.0230	0.0430
0.175	0.350	0.7472	0.1870	0.0427	0.0230	15.30	6.0	0.575	0.0421	0.545	0.0236	0.0420
0.200	0.361	0.7475	0.1865	0.0421	0.0237	17.50	4.2	0.405	0.0417	0.382	0.0241	0.0416
0.250	0.375	0.7480	0.1860	0.0410	0.0249	21.90	2.5	0.240	0.0408	0.227	0.0251	0.0409
0.300	0.381	0.7481	0.1860	0.0407	0.0251	26.30	2.0	0.191	0.0405	0.182	0.0253	0.0406
0.350	0.388	0.7483	0.1859	0.0404	0.0255	30.70	1.5	0.144	0.0403	0.136	0.0256	0.0402

conducted in a packed bed catalytic reactor as shown schematically in Fig. 1. The feed enters with a mass velocity G, partial pressure P' for the key component (say A), and leaves with a partial pressure p° for the same component. The various partial pressure gradients existing around a differential bed of this reactor are represented in Fig. 2. Detailed reference to this figure will be made later in this section, but it may be noted at this stage that the driving force for the reactant A to diffuse from the bulk of the stream to the catalyst surface is $(p - p_i)_A$ and the corresponding HTU is given by:

$$HTU = \frac{dZ}{dp/(p-p_i)_A} = \frac{Z}{\int \frac{dp}{(p-p_i)_A}} \quad \ldots.(1)$$

Hurt combined this HTU with a height of catalytic unit HCU defined by:

$$HCU = \frac{Z}{\int \frac{dp}{(p_i-p^*)_A}} \quad \ldots.(2)$$

where p^* is the partial pressure of A in equilibrium with p (determined by the equilibrium constant), and obtained the expression,

$$HRU = \frac{Z}{\int \left(\frac{dp}{p-p^*}\right)_A} = (HTU + HCU) \quad \ldots.(3)$$

It is apparent from Equation (3) that the exponent of the driving force term in the definition of HCU (Equation (2)) has been assumed to be unity, and also that the HTU for the products has been combined in the expression for HCU.

Let us now examine the situation more rigorously. It will be assumed that reaction (a) takes place under isothermal conditions and that component B is present in such excess as to be kinetically ineffective. It would appear logical to divide the overall driving force into components, each of which would define a distinct rate process. These rate processes may be expressed in terms of the height required to perform a given transfer (or conversion) service. The overall height could then be evaluated by summing up the individual heights. This procedure obviates the necessity to assume first-order kinetics, as has been done in Equation (3).

A reference to Fig. 2 shows that the partial pressures are defined over the ordinate p and the variations in catalyst depth over the space co-ordinate z. It is possible to identify an equivalent fluid film of thickness z_g around the catalyst bed of thickness dz. The bulk partial pressures for the reactant A and product C are indicated by ordinates p_A and p_C. Under steady-state conditions, the rate of diffusion of the reactant across the equivalent film on to the catalyst surface is governed by the partial pressure gradient $(p - p_i)_A$. At the interface it undergoes reaction, the driving force for which may be given by the term $(p_i - p_i^*)_A$. In as much as operating conditions dictate the extent of residence time for the chemical reaction to proceed on the surface, the reaction need not necessarily go to equilibrium. As such it is possible to visualise two effective partial pressure terms $p_i^E{}_A$ and $p_i^E{}_C$ which get stabilised at the interface under steady-state conditions and which provide a measure of departure from equilibrium. It is thus evident that the outward diffusion of the product must be dictated by the potential $(p_i^E - p)_C$. Further, it is possible to define an overall driving force $(p - p^*)_A$ which would be non-linear in the direction of bulk flow, with the point $p = p_i$ and $z = z_g$ lying in its path, however.

The following equations may now be written for the three steps comprising the overall rate process:

(1) *Diffusion of* A *from bulk to interface.* The expression for this is identical with Equation (1), except that HTU is replaced by HTU_1.

(2) *Chemical reaction*

$$HCU = \frac{z}{p_i^0 \int_{p'} \frac{dp}{(p_i-p^*)_A^n}} \quad \ldots.(4)$$

(3) *Diffusion of* C *from interface to bulk*

$$HTU_2 = \frac{z}{p^0 \int_{p'} \frac{dp}{(p_i^E-p)_C}} \quad \ldots.(5)$$

The three equations given above can then be combined to give HRU:

$$HRU = \frac{z}{p^0 \int_{p'} \frac{dp}{(p-p^*)_A^m}} = (HTU_1 + HCU + HTU_2) \ldots.(6)$$

The magnitude of the exponent m depends on the order of the reaction n; it may be calculated by first determining HRU by summing up the individual heights and then evaluating the integral $\int_{p'}^{p^0} \frac{dp}{(p-p^*)_A^m}$ using a trial and error procedure by assigning arbitrary values for m.

Evaluation of Individual Height Units

The following principal data are required for estimating the HTU's and HCU: reaction equilibrium constant; conversion as a function of bed height, in experimental reactor, at one or more feed rates; and feed composition. The first step is to obtain instantaneous rates from the conversion vs. bed height data, at any given feed rate. The catalyst weight for a given height being known, a curve of W/F vs. x can be drawn. Graphical differentiation of this curve gives the reaction rate r which can then be plotted as a function of x.

HTU_1. Under steady-state conditions, the instantaneous rate may be related to the mass transfer coefficient by the expression:

$$r = -k_g a (p - p_i)_A \quad \ldots.(7)$$

k_g of this equation may be evaluated from the well-known j_d correlation:

$$j_d = \left(\frac{k_g \cdot p_f \cdot M_m}{G}\right)\left(\frac{\mu}{\rho D_m}\right)^{\frac{2}{3}} \quad \ldots.(8)$$

In using Equation (8) it would be necessary to estimate the mean effective diffusivity D_m of the key reactant. This may be done by appropriately combining the binary diffusivities in the usual manner. The value of j_d to be used in Equation (8) may be determined from the mass transfer equations of HOUGEN and co-workers[1, 7]:

$$j_d = 1.82\left(\frac{D_p \cdot G}{\mu}\right)^{-0.51} \text{ for } \frac{D_p \cdot G}{\mu} < 350 \ldots.(9)$$

$$j_d = 0.989\left(\frac{D_p \cdot G}{\mu}\right)^{-0.41} \text{ for } \frac{D_p G}{\mu} > 350 \ldots.(10)$$

Where the fluid composition does not vary appreciably with catalyst depth in the experimental reactor, the physical properties may be estimated as weighted averages at the mean composition. Thus j_d will have a single value for the entire bed. But in cases where the composition changes significantly over the bed depth, j_d should be evaluated at each of the available values of z. Further, for reactions in which there is an appreciable change in the number of moles, the value of G cannot be assumed constant and will have to be estimated for each depth. $(p - p_i)_A$ may then be calculated from Equation (7) at various points in the reactor and used in the graphical integration for obtaining HTU_1.

HCU. This is a measure of the resistance to chemical reaction on the surface of the catalyst, and consequently one is concerned only with partial pressures at the interface. If the order of the reaction is known, the driving force term $(p_i - p_i^*)_A^n$ can be readily computed since p_{iA} may be determined from HTU_1 calculations and $p_i^*{}_A$ from a knowledge of the reaction equilibrium constant. Thus the integral of Equation (4) may be evaluated to obtain *HCU*.

HTU_2. In this case we are concerned with diffusion of the products from the surface to the bulk and, since a positive driving force in this direction exists only for the product C, HTU_2 should logically be based on C. In estimating the driving force for this step, allowance must be made for the contact efficiency of the catalyst which may be defined as:

$$E = \left(\frac{p_i - p_i{}^E}{p_i - p_i{}^*}\right) \quad \ldots.(11)$$

Equation (11) represents a point efficiency and, as explained earlier, is a measure of the departure from equilibrum of the surface reaction. When the contact efficiency is unity, $p_i{}^E = p_i{}^*$. It may be noted that this definition of contact efficiency bears close resemblance to the Murphree local plate efficiency in a distillation column.

$p_i{}^E$ may now be calculated as follows. Under steady-state conditions, the rate of diffusion of the reactants to the interface must be equal to the rate of diffusion of the products away from the interface. Thus:

$$-r_A = r_C \text{ or}$$

$$-r = k_{gA} \cdot a\,(p - p_i)_A = k_{gC} \cdot a\,(p_i{}^E - p)_C \quad \ldots.(12)$$

k_{gC} may be calculated using a Schmidt group based on the mean effective diffusivity of C. The value of $(p_i{}^E - p)_C$, and therefore of $p_i{}^E{}_C$, may then be computed, leading to the solution of Equation (5) for HTU_2 and to the evaluation of contact efficiency.

TABLE II—Estimated Physical Properties

Property	Average Value at 360°C	Remarks
(1) Density	0.033 lb/cu ft	
(2) Viscosity	0.072 lb/ft hr	Generalised chart[6]
Diffusivity		
(3) D $SO_2 - N_2$	1.35 ft²/hr	Gilliland's Equation[3]
(4) D $SO_2 - O_2$	1.36 ,,	,,
(5) D $SO_2 - SO_3$	0.86 ,,	,,
(6) D $SO_3 - O_2$	1.42 ,,	,,
(7) D $SO_3 - N_2$	1.40 ,,	,,
(8) D_m SO_2	1.34 ,,	Weighted mean of 3, 4 and 5
(9) D_m SO_3	1.44 ,,	Weighted mean of 5, 6 and 7
(10) M_m	27.40 ,,	—

TABLE III—Relative Contributions of the Chemical and Diffusional Resistances

Term	Height Unit, ft	% Total Resistance
HTU_1	0.0205	1.30
HCU	1.5600	97.50
HTU_2	0.0194	1.20

Illustrative Example

In order to test the applicability of the foregoing concepts, a practical example has been selected from the literature. The experimental work chosen refers to the catalytic oxidation of SO_2 over platinum catalyst in a fixed-bed reactor.[5] The following relevant data are available in addition to the conversion vs. bed depth data: mass velocity = 350 lb/sq ft/hr; average reactor temp. = 360°C; catalyst bulk density = 64 lb/cu ft; surface area of catalyst = 5.12 sq ft/lb; catalyst pellet diam. = 0.0128 ft; inlet composition = 6.5 mol per cent SO_2 and 93.5 per cent air; reactor diam. = 2.06 in. i.d.; and the reaction equilibrium constant > 400.

The following two basic plots are prepared from the available $x - z$ data: (a) $x - W/F$ plot, and (b) $r - x$ plot by differentiating the curve of plot (a). The plots are not reproduced here. From a knowledge of the fluid composition at the inlet, its variation over the catalyst height is then calculated; these are shown in columns 3, 4, 5 and 6, Table I. The numerical calculations necessary for estimating the *HTU*'s and *HCU* are based on weight-averaged physical properties. Since in this case a large excess of inert nitrogen as well as of oxygen is present, and changes in composition are primarily due to changes in SO_2 and SO_3 concentrations, it is reasonable to calculate the physical properties at the mean composition of the stream over the entire bed. The physical properties calculated in this manner are summarised in Table II.

Evaluation of HTU_1. From Equations (7), (8) and (9), the driving force term $(p - p_i)_{SO_2}$ is estimated for various values of r, and the results are listed in column 9, Table I. Considering the large excess of inert in the feed, G is assumed constant over the entire bed height. The determination of HTU_1 from Equation (1) then involves graphical integration of the term $dp/(p - p_i)_{SO_2}$ between the limits p = 0.0404 and p = 0.0547 over a height of 0.275 ft. Thus HTU_1 = 0.0205 ft.

Evaluation of HCU. In this case a simplification is possible considering the very large positive value (>400) for the reaction equilibrium constant. The equilibrium partial pressure of SO_2 at the catalyst surface, $p_i{}^*{}_{SO_2}$, may be taken as zero and *HCU* obtained by evaluating the integral of Equation (4) between the limits 0.0403 and 0.0481 over a bed height of 0.275 ft. The reaction order n may be assumed to be unity, but it should be noted that the method applies for any value of n. Thus HCU = 1.56 ft.

Evaluation of HTU_2. In estimating this term, Equation (12) may be re-written for this reaction as:

$$(k_g \cdot a)_{SO_2} \cdot (p - p_i)_{SO_2} = (k_g \cdot a)_{SO_3} \cdot (p_i{}^E - p)_{SO_3} \quad \ldots.(13)$$

in which all terms except $(k_g \cdot a)_{SO_3}$ and $p_i{}^E{}_{SO_3}$ are known. Estimation of $(kg \cdot a)_{SO_3}$ involves the evaluation of the mean effective diffusion coefficient for SO_3 diffusing through a stagnant mixture of SO_2, N_2 and O_2. Using this value of mean diffusivity (Table II) the Schmidt group is calculated, which, on substitution in Equation (8), gives $(k_g \cdot a)_{SO_2}$ = 11.0. The driving force $(p_i{}^E - p)_{SO_3}$ for outward diffusion of SO_3 is then given by:

$$(p_i{}^E - p)_{SO_3} = \frac{(k_g \cdot a)_{SO_2}}{(k_g \cdot a)_{SO_3}} \cdot (p - p_i)_{SO_2} = 0.945\,(p - p_i)_{SO_2}$$

$\ldots.(14)$

The values of $(p_i^E - p)_{SO_3}$ obtained from Equation (14) are recorded in column 11, Table I. Thus:

$$HTU_2 = (0.35-0.075) \div \frac{1}{0.945}\int_{0.0506}^{0.0404} \frac{1}{(p_i^E - p)_{SO_3}} \cdot dp$$

$$= 0.0194 \text{ ft}$$

The values of the various height terms calculated above and their respective contributions to the overall reaction resistance are shown in Table III. It is clear that, in this case, the major resistance is due to chemical reaction. Purely from the kinetic point of view, therefore, it would appear desirable to carry out the reaction at a lower mass velocity. This problem is further discussed in the next section.

Contact efficiency. It has been observed earlier that the departure from equilibrium of the surface reaction is primarily due to the inadequate residence time allowed for any differential contact between the reactants and catalyst mass. The reaction should go to completion over an extended period of time or depth of catalyst under steady conditions. It is therefore evident that, if one were to decrease the superficial mass velocity of the fluid with the object of increasing the residence time, the conversion will not increase in proportion, not only because of the influence of the order of the reaction but also (and mainly) because of the pronounced effect of the mass velocity on *HTU*. Fig. 3 schematically represents the effect of *G* on *HTU* and *HCU*. It is apparent that there is an optimum value of *G* corresponding to the minimum value of *HRU*.

For the example under examination, the contact efficiency may be computed based on the component SO_2. In column 12, Table II, are listed the actual partial pressures of SO_3 at the interface evaluated from the $(p_i^E - p)_{SO_3}$ values listed in the previous column. From a material balance on the interface, it is possible to compute the effective partial pressure of SO_2, $p_i^E{}_{SO_2}$. Assuming $p_i^*{}_{SO_2}$ to be zero, the contact efficiency for this system may be given by:

$$E = \left(\frac{p_i - p_i^E}{p_i}\right)_{SO_2}$$

The numerical value of the contact efficiency decreases from about 6.0 per cent at initial conversions to nearly zero when the conversion stabilises to an almost constant value.

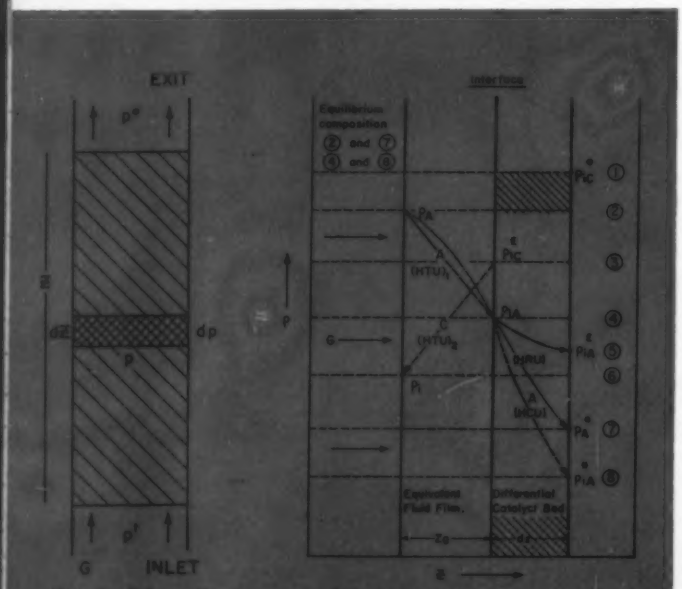

Fig. 1. Schematic diagram of catalyst tube

Fig. 2. Partial pressure gradients in and around a differential catalyst bed.

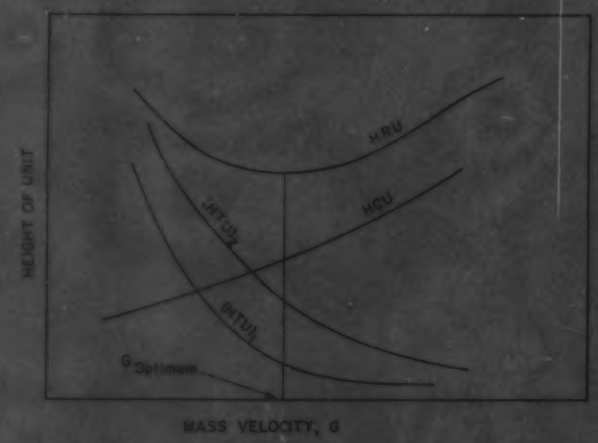

Fig. 3. Determination of optimum mass velocity of feed.

Summary and Conclusions

(1) A method is proposed for separating the chemical and mass transfer effects in a chemical reactor.

(2) The estimation of the mass transfer resistance for the diffusion of the reactants, expressed as HTU_1, follows a straightforward procedure using the correlations of HOUGEN and co-workers.

(3) In estimating the mass transfer resistance for the products, the concept of effective partial pressures (due to inadequate residence time) is introduced and a contact efficiency is defined which is a measure of the insufficiency of contact.

(4) A method is indicated by which these effective partial pressures may be estimated and HTU_2 (for the products) evaluated.

(5) The *HCU* term of the overall resistance may be estimated without any restriction on the reaction order, and combined with the other height terms to obtain *HRU*. Then, by a trial and error procedure, the order of the overall step may be determined.

(6) The proposed method is illustrated by evaluating the three resistances for an SO_2 converter.

(7) The rigorous procedure outlined in this paper is applicable to isothermal reactors or to adiabatic reactors where the feed rate and inlet temperature are of such magnitude as to maintain practically isothermal conditions.

(8) The optimum feed velocity, as calculated by this method (Fig. 3), should be differentiated from the economic feed velocity which is determined from a balance between operating cost and reactor cost. Quite often the economic feed velocity may be different from the kinetically determined optimum velocity.

REFERENCES

1. Gamson, B. W., Thodos, G., and Hougen, O. A., *Trans. Am. Inst. Chem. Engrs.*, **39**, 1 (1943).
2. Gilliland, E. R. *Ind. Eng. Chem.*, **26**, 681 (1943).
3. Hurt, D. M., *Ind. Eng. Chem.*, **35**, 522 (1943).
4. Lampichler, F. G., *Ind. Eng. Chem.*, **30**, 578 (1938).
5. Olson, R. W., Schuler, R. W., and Smith, J. M., *Chem. Eng. Prog.*, **46**, 614 (1950).
6. Uyehara, O. A., and Watson, K. M., *Natl. Petroleum News, Tech. Sec.*, **36**, R764 (Oct. 4, 1944).
7. Wilke, C. R., and Hougen, O. A., *Trans. Am. Inst. Chem. Engrs.*, **41**, 445 (1945).

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FLOW CHARACTERISTICS OF DILUTE SMALL PARTICLE SUSPENSIONS

A study of the influence of effective density ratio and concentration upon horizontal settling velocity

by R. C. CAIRNS, K. R. LAWTHER and K. S. TURNER*

Introduction

A PROGRAMME of work on the dynamic behaviour of small particle suspensions has been carried out by the Australian Atomic Energy Commission (A.A.E.C.) because of the interest in a power reactor fuel consisting of fissile powder suspended in a liquid metal. The advantages of this type of fuel system have been dealt with by ALDER.[1] Early in the Australian programme fissile uranium powder suspended in molten sodium was selected for detailed theoretical study. The atomic ratio of 1 to 100 of uranium to sodium was chosen for the concentration, and the particle size envisaged for the powder was less than 10 microns.

It was appreciated that very many difficulties were likely to be encountered, due to settling during flow through bends, valves and even straight pipes. This could lead to unpredictable accumulation of fissile material in local dead spots, rapid changes in concentration and unstable circuit operation.

An examination of the literature revealed that very little was known theoretically about the behaviour of suspensions of fine, dense, insoluble powders in a relatively light fluid.

Previous A.A.E.C. work[2, 3, 4, 5] has shown that dilute suspensions of fine, dense solids behave as normal liquids above the horizontal settling velocity, provided the density and viscosity used to define them relate to the suspension. It was shown that high values of Reynolds number were required to maintain tungsten powder and barium sulphate in aqueous suspension in a horizontal pipe, contrary to previously accepted concepts.[6, 7] A correlation of the existing data on horizontal settling velocities has been presented, together with some results on particle concentration profiles in a flowing stream.

Theory does not enable predictions to be made on the effect of pipe diameter or concentration on the horizontal settling velocities, or whether Reynolds number is a measure of suspension turbulence. Additional data were required to determine these effects and are presented here.

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Symbols Used

c = concentration, per cent by volume;
d_{50} = mean particle diameter such that 50 per cent by weight of particles are less than d_{50}, ft;
D = pipe diameter, ft;
g = acceleration due to gravity, 32.2 ft/sec^2;
I = intensity of collimated gamma radiation incident on the scintillation counter; I_A = through air only;
N = number of counts registered per sec on the scintillation counter unit; N_A = through air only;
Re = Reynolds number, dimensionless;
V = horizontal settling velocity, ft/sec;
V_m = moving bed velocity, ft/sec;
V_s = stationary bed velocity, ft/sec;
ρ_s = solid density, lb/ft^3;
ρ_l = liquid density, lb/ft^3;
τ = paralysis, or effective dead time of the scintillation counting equipment; and
μ_l = liquid viscosity, lb/(ft)(sec).

Attempts have been made in the literature to theoretically derive particle concentration profiles or distributions of flowing suspensions.[8, 9] The theories are based on the assumed equality between the rate of fall under gravity of a particle of given size, density, and shape, and the rate at which the particle is lifted by the turbulent action of the stream. To evaluate the concentration distribution across a cross-section, it is necessary to assume that the presence of the particles in suspension does not affect the velocity distribution.[8] Some assumption is needed also for the relationship between eddy diffusivity of momentum and suspension transport.[9, 10]

With these assumptions, it is possible to draw curves of the distribution relative to some reference level which, unfortunately, cannot be the bed surface unless further simplifying assumptions are made. When dealing with suspensions whose particles have a size distribution, theoretical solution of the equations becomes a complex statistical problem.

Experimental investigation of mean particle concentra-

tion profiles was therefore attempted. It was desired to know whether large concentration differences existed in suspensions in the fully suspended state in vertical and horizontal flow. This information was required, since it was realised that the operation of a suspension reactor will be influenced by changes in the concentration distribution across each of the core tubes, as well as concentration changes in fuel fed to the core.

It has been reported by WOLFE and MURPHY[11] that a condition called "coring" occurs with some suspensions in upward vertical flow. Here the solid phase collects at the centre of the pipe in a core and maintains a higher average velocity than the fluid.

Since the core of the Liquid Metal Fuelled Reactor (LMFR) would consist of vertical channels, it was required also to investigate the behaviour at the entry into a vertical pipe from a horizontal pipe through a smooth 90° elbow, to establish whether the suspension is uniform throughout the vertical length, and to determine whether the condition referred to as "coring" occurs for the system studied.

Data are given here of concentration profiles for a typical dense particle suspension flowing through a horizontal pipe, upwards through a vertical pipe, and through a smooth 90° elbow connecting these. The system used was an approximately 8 per cent by weight suspension of tungsten powder in water, which corresponds to the concentration of 1 atom of uranium to 100 atoms of sodium in the LMFR system.

The Effect of Concentration and Pipe Diameter on the Horizontal Settling Velocity

Apparatus

For a variety of pipe sizes and concentrations, data have been collected for the systems red lead-water, barium sulphate-water, tungsten-water and talc-water. The solids used covered a range of density of 2.7 to 19.3 g/cc, and were readily available in the sub-sieve size range.

Transparent Dicon pipes were used of ¾-in., 1-in., 1½-in. and 2-in. nominal internal diameter and mean concentrations of approximately 5, 10 and 15 per cent by weight of barium sulphate and red lead, and approximately 9 per cent by weight of tungsten and talc were circulated.

The loop used is shown in Fig. 1 and was similar to that used for previous work on barium sulphate.[3] The loop was modified to allow for the interchange of different diameter test lengths in the top horizontal section.

The diameter of each test pipe was determined accurately. The variations in pipes diameter were negligible. The lengths of the test pipe were approximately 10 ft, and the full lengths were observed to determine the bed condition. A 500-watt Barton Foto-Spot spotlight was used for illumination.

The method of loop operation and collection of results was similar to that used previously,[3] except that samples were usually taken during the timed discharge for moving bed conditions and a stabilising period of 15 min was required when the ¾-in. pipe was in circuit.

Particle size distributions of all the powders were determined before use and the results are given in Table I. The Andreasen pipette method with water as suspending medium was used for the barium sulphate, tungsten and talc, but it was not possible to obtain reproducible results for the red lead. The red lead, however, was 95 per cent by weight less than 325 mesh Tyler (43 microns), wet screened.

The talc suspension was found to contain a small amount of impurity which was shown (by spectrographic analysis) to contain iron. This tended to obscure the formation of a bed. The bulk of this impurity was removed by sedimentation from the flowing suspension in the horizontal 2-in. test length, but this involved some loss of talc, giving an altered particle size distribution.

To determine the new particle size distribution, Andreasen samples were taken directly from the discharge stream. This was done after removal of the impurity and also after completion of the experimental work. The analyses are given in Table I.

Particle size analyses were also obtained on the dry powders by the Sharples Micromerograph, and these results are given in Table I for comparison. In all cases, the Andreasen results indicate larger particle diameters than the Micromerograph results, which again illustrates the lack of agreement between different methods of particle size analysis for sub-sieve particles.

Demineralised water was used for all experiments. No difficulty was experienced in preparing the suspensions, or resuspending the solid after closing down.

The supernatant liquid was analysed after the experimental work for each system, and the dissolved solids were found to be less than 0.1 per cent by weight in all cases.

Details of all experimental results are given elsewhere.[12]

Results and Discussion

The horizontal settling velocity was determined by reducing the flow rate and observing the point at which a moving bed appeared, as well as the point at which a stationary bed appeared in the test length. The number of runs from which means for settling velocities were evaluated varied from 2 to 12.

Both moving and stationary beds were readily obtained for most of the systems and pipe sizes used. Because of the measurable differences between mean velocities for moving and stationary beds, both have been reported. The only instances in which both beds were not readily obtained were for the runs with tungsten in ¾-in. and 1-in. tubes, where the moving bed condition was not reproducible. The stability of a moving bed for the other runs was frequently confirmed by running the loop at moving bed conditions in the test pipe for a period of 30 min. Striations[8] were observed in all cases before and during settling.

Effect of Concentration

For the LMFR system, only dilute suspensions are required. For the suspension containing 1 atom of uranium to 100 atoms of sodium at 500°C, the concentration of uranium is approximately 9.2 per cent by weight or 0.5 per

TABLE I

Per cent undersize by weight	Stokes, diameter microns											
	Red lead powder before use		Barium sulphate powder before use		B.H.P. tungsten powder before use		Talc powder as received		Talc after purification		Talc after use	
	Andreasen	Micromerograph	Andreasen	Micromerograph	Andreasen	Micromerograph	Andreasen	Micromerograph	Andreasen	Micromerograph	Andreasen	Micromerograph
100	—	29	—	20	—	15	—	52	—	—	—	—
95	—	7.8	—	8.4	—	10	—	31	—	—	45	—
85	—	4.4	35	6.1	—	7.9	43	24	32	—	27	—
70	—	3.3	33	4.8	—	6.1	32	19	24	—	20	—
50	—	2.3	30	3.7	16	4.8	25	15	17	—	14	—
30	—	1.8	26	2.9	13	3.7	16	11	10.5	—	8.3	—
15	—	1.4	20	2.3	9.2	2.8	8.8	8.4	6.2	—	4.5	—
5	—	1.1	10	1.8	5.7	1.8	4.8	5.7	—	—	—	—
0	—	0.96	—	1.4	—	1.0	—	2.4	—	—	—	—

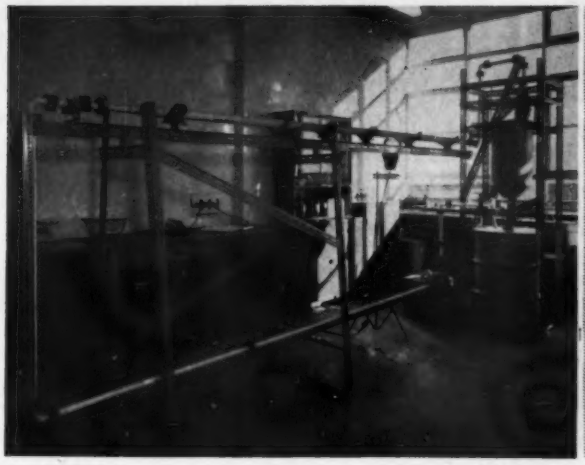

Fig. 1. Photograph of the loop operating with 2-in. test pipe installed.

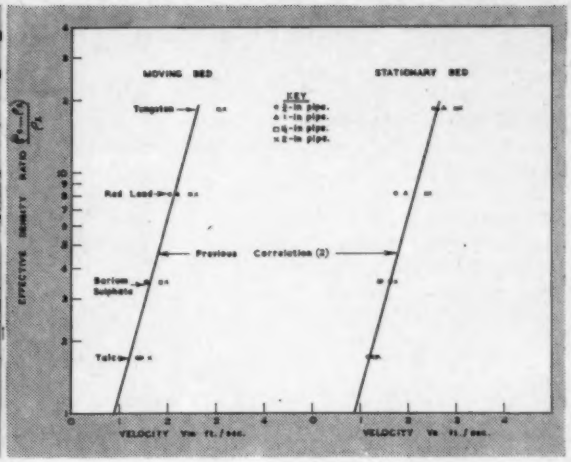

Fig. 2. Effective density ratio v. horizontal settling velocity.

cent by volume. For the UBe_{13}-Na system,[1] the concentration is approximately 13 per cent by weight or 3 per cent by volume.

For the barium sulphate-water system, which simulates in many respects a UBe_{13}-Na suspension, the concentration of solids circulated was varied between approximately 5 and 16 per cent by weight, or 1 and 4 per cent by volume, for each of the four pipe sizes used. In some cases, there was no effect of concentration on the velocity for the formation of a moving bed or stationary bed, while in others there was a small increase in velocity with concentration. The results for the red lead-water system, in which the concentration was varied from approximately 7 to 15 per cent by weight or 0.8 to 1.9 per cent by volume showed again that the concentration has little effect on the horizontal settling velocity for moving and stationary beds. The maximum increase was of the order of 0.2 ft/sec. Although concentration appears to have a small effect, it is considered to be negligible over the concentration range studied and mean velocities and concentrations were evaluated for use in later correlations.

It may be concluded that for dilute small particle suspensions with volume concentrations of up to several per cent, the horizontal settling velocities are almost independent of the concentration circulating.

Effect of Pipe Diameter

In Fig. 2 horizontal settling velocity is plotted against effective density ratio on semi-log paper. This method of correlation has been previously proposed,[4] but it can be seen that the pipe diameter variation has caused a spread of the points for each effective density ratio.

The results were replotted on log-log paper as horizontal settling velocity versus internal pipe diameter for constant effective density ratio and straight lines fitted to the points for each system for both moving and stationary bed conditions. The mean slope of the lines was found to be 0.2.

$$\text{Hence } V \propto (D)^{0.2} \qquad \ldots . (1)$$

Effect of Solid Density

The results were also plotted on log-log paper as horizontal settling velocity versus effective density ratio for constant pipe diameter and straight lines fitted to the points for each pipe. The mean slope for the stationary bed condition was slightly greater than that for the moving bed condition, but this difference was considered insignificant, and a mean slope of all the lines was obtained. This was found to be 0.3 and hence:

$$V \propto [(\rho_s - \rho_l)/\rho_l]^{0.3} \qquad \ldots . (2)$$

Expression for Horizontal Settling Velocities

The results were recalculated as shown in Table II and horizontal settling velocity was plotted against $D^{0.2} \times [(\rho_s - \rho_l)/\rho_l]^{0.3}$. This is shown in Fig. 3 and equations were obtained for V_m and V_s.

These are:

$$V_m = 1.9D^{0.2} \times [(\rho_s - \rho_l)/\rho_l]^{0.3} \qquad \ldots . (3)$$

$$V_s^{0.85} = 1.6D^{0.2} \times [(\rho_s - \rho_l)/\rho_l]^{0.3} \qquad \ldots . (4)$$

These equations apply for pipe diameters of $\frac{1}{4}$ in. to 2 in. and effective density ratios of 1.7 to 18.3.

The UO_2-NaK data of ABRAHAM *et al.*[12] have also been plotted on the moving bed graph in Fig. 3. ABRAHAM's data correspond more to the moving bed condition than to the stationary bed condition, because of the radiometric method of detecting suspended flow used by ABRAHAM. The agreement is good.

The lime-water point of SETTLE and PARKINS, quoted by SPELLS,[14] has been plotted on the moving bed graph in Fig. 3. Agreement is poor. However, more recent information[15] has been obtained, which shows that SPELLS' data and the data from the A.A.E.C. investigations cannot be compared.

It appears[15] that the lime-water settling velocity data were not obtained by direct observation, since none of the test installations used by SETTLE and PARKINS contained any transparent section. For the more dilute suspensions, the settling velocity was obtained from log pressure drop versus log velocity curves, which cannot be conclusive.[5]

SETTLE and PARKINS state that it was not possible to determine the velocity at which a moving or stationary bed formed. It is interesting to note also that the particle sizes, as given by SPELLS,[14] are larger than those used in this investigation.

For these reasons, the lime-water point of SPELLS[14] was rejected in arriving at Equations (3) and (4).

Attempts to provide a correlation in terms of dimensionless groups were unsuccessful. This is attributed to the values used for the particle diameter. The method used to evaluate the particle diameter was the Andreasen pipette

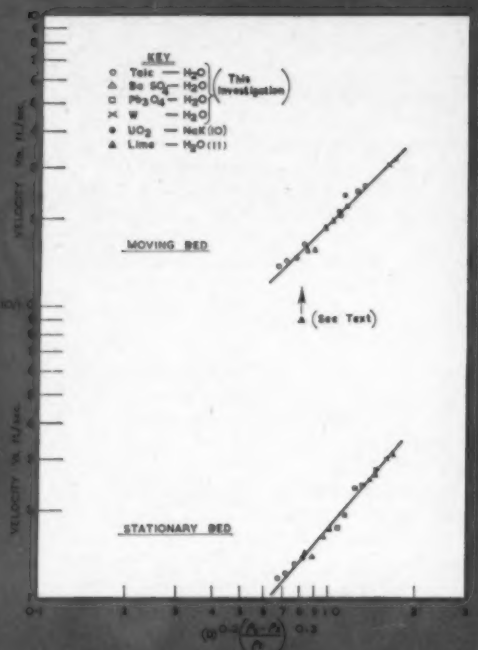

Fig. 3. Horizontal settling velocity v. $(D)^{0.3}\left(\frac{\rho_s-\rho_l}{\rho_l}\right)^{0.3}$.

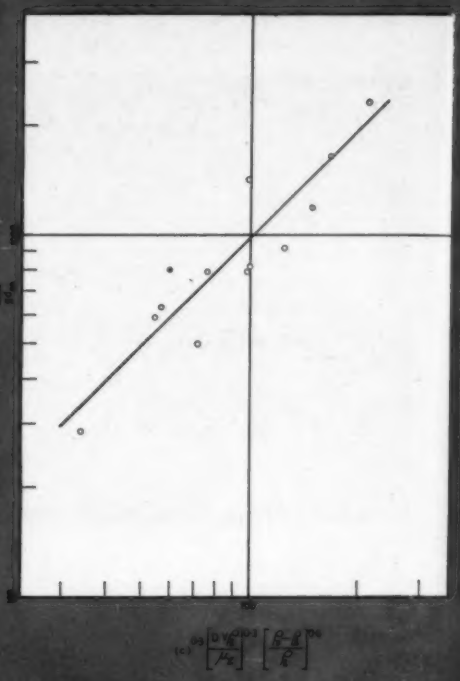

Fig. 4. Correlation for larger particles.

method, but different methods give different results for sub-sieve particles and there may be a more suitable method. No method is known at present which gives the effective diameter of sub-sieve particles settling from flowing suspensions.

In this experimental work, the pipe diameter was varied from 2 in. to $\frac{1}{4}$ in., a ratio of 2.7 to 1. It is to be noted that for a given velocity and suspension this means that the Reynolds number was varied by a ratio of 2.7 to 1. If the Reynolds number of a suspension is a measure of turbulence, as it is with a homogeneous fluid, then it would be expected that the horizontal settling velocities would be very dependent on the Reynolds number, and decrease with increase in pipe diameter to maintain the same Reynolds number.

However, it has been shown that the horizontal settling velocity increases with $D^{0.3}$, i.e., $Re^{0.3}$. In view of this, it would appear that the bulk Reynolds number of a suspension is not a measure of turbulence, or degree of suspension.

An analysis has been made of the data of SPELLS[14] for larger particles, and an empirical correlation has been derived,[16] based largely on the results from this investigation. This dimensionless correlation, shown in Fig. 4, is an improvement on that suggested by SPELLS, but applies only to particles having mean diameters of 242 to 380 microns and a density of 2.6 g/cc. The equation of the line shown in Fig. 4 is:

$$V^2/gd_{50} = 9.8\,(c)^{0.3}\,[DV\rho_l/\mu_l]^{0.3}\,[(\rho_s - \rho_l)/\rho_l]^{0.6} \quad \ldots . (5)$$

It has not been possible to provide a generalised equation for the horizontal settling velocity for suspensions covering all particle sizes.

Until a method of evaluating an effective or working diameter for sub-sieve particles is available, it is felt that separate equations will be needed to correlate small and large particle results. In this regard, the recent work of DALLAVALLE *et al.*[17] shows considerable promise, but as yet the application of Dallavalle's equation for a particle "working" diameter is not possible in flowing systems.

Concentration Profiles in a Flowing Suspension

Apparatus

A radiometric method[18] was used to measure concentration distributions and, to facilitate measurements, the tungsten suspension was pumped through a pipe of square cross-section. The loop used, which was similar to that shown in Fig. 1, and the radiometric traversing equipment have been described elsewhere.[5, 19, 20]

Iridium 192 is suitable for use in the measurement of high tungsten concentrations because of the high energy gamma rays in its spectrum, and this radio-isotope has been used for concentration measurements with the settled bed condition.[5, 19] For low concentrations in the 1-in. square perspex pipe used, thulium 170 is more suitable, being a source of low energy gamma rays. The results reported are for the lower concentrations obtained in fully suspended flow using thulium 170.

For measurements with horizontal flow, an upstream calming length of 100 equivalent diameters was used with a downstream length of 20 equivalent diameters.

For measurements with vertical flow and flow at a 90° elbow, a vertical perspex pipe of 1-in. square section, 4 ft 8 in. long was preceded by a smooth 90° elbow of 1-in. square section with a centre-line radius of curvature of 4-in. A 5 ft 4 in. length of horizontal square pipe was joined to the upstream end of the elbow.

The concentration gauge, utilising the radiometric technique, measured the average concentration of tungsten in suspension at selected positions across a plane at right angles to the direction of flow through the square pipe. Calibration of this gauge has been reported previously.[18] Fig. 5 shows the traversing equipment set up at the elbow. A gamma-emitting source in a lead bomb was set up on one side of the square pipe, so that the gamma beam passed through the perspex pipe containing the flowing suspension, and was then collimated through a $\frac{1}{16}$-in. hole in a 2-in. thick lead block on the other side of the square pipe before being detected by a sodium iodide crystal and scintillation counter. The number of counts shown on the scaler in a

Fig. 5. Photograph of traversing apparatus set up at the elbow.

given time is proportional to the intensity of gamma radiation incident on the crystal. This depends on the average tungsten concentration of the suspension at the position through which the radiation passed prior to passing through the $\frac{1}{16}$-in. collimating hole.

The whole arrangement, including lead source holder, collimating block and scintillation head, was mounted on a table which could be moved at right angles to the pipe so that the gamma radiation could be passed through the square pipe at various distances from the bottom. The beam could be traversed right across the pipe and clear of it and a reference scale on the base was calibrated to indicate the vertical displacement.

The internal dimensions of the pipes in the region through which the gamma beam passed were measured by the Metrology Division of the C.S.I.R.O. National Standards Laboratory, Chippendale, Sydney, using an air gauge technique. The widths of the pipe at the traversing plane for horizontal flow varied from 0.966 ± 0.001 in. to 1.001 ± 0.001 in. measured at three places located centrally, $\frac{1}{4}$-in. apart, for a temperature of 68°F. The variation in widths at the centre of the elbow in the direction of the gamma beam for three positions located centrally, $\frac{1}{4}$ in. apart and a temperature of 68°F, were 0.969 ± 0.002 in. to 0.978 ± 0.002 in.

The tungsten powder used had the particle size analysis given in Table I. Spectrographic analysis of samples of the powder before use showed only trace quantities or less of Mo, Fe, Ti, Cr, Ca, Ni, Co and V. The elements Mg, Al, Mn, Zr and Cu were not detected.

Difficulty was experienced in obtaining sufficient agitation in the main tank to maintain complete suspension of the powder and yet prevent entrainment of air bubbles. Precautions taken to exclude entrainment were maintenance of a high suspension level in the tank and careful adjustment of the stirrers in the tank. Before and after several of the runs, checks were made to determine whether significant amounts of air were being entrained. The loop valve was closed quickly and the pipes inspected for the presence of air bubbles.

To ensure that any concentration profiles obtained were not due to irregularities in the pipe itself, traverses were taken across the pipe and the 90° elbow at the corresponding positions with the pipe filled with sodium tungstate solution. The solution used contained approximately 8 per cent tungsten by weight corresponding to the average concentration of the suspension.

Results and Discussion

Count rates obtained on the scintillation counter assembly were corrected for paralysis or effective dead time. The computed count rate is directly proportional to the intensity of collimated gamma radiation, I, incident on the detecting crystal, and is equal to $N/(1 - N\tau)$. The relative count rate is then:

$$I/I_A = N(1 - N_A\tau)/N_A(1 - N\tau) \qquad \ldots . (6)$$

The value of N_A used in this equation was the mean of the reference counts in air before and after each set of readings of N.

The calibration data for the thulium source have been published previously[18] in terms of the ratio of the count rate through the pipe of tungsten suspension to the count rate through the pipe filled with demineralised water only, versus mass of tungsten per unit volume of suspension. This was converted to the more convenient calibration of count rate relative to air versus per cent by weight tungsten in suspension for the straight square pipe used in the horizontal and vertical positions and for the bend.

Because of the small variation in dimension of the straight square pipe in the direction of the gamma beam, no correction was necessary to allow for change in thickness of the suspension. The error corresponded to less than 1 per cent correction to the relative count rate for the square pipe, and was neglected. From readings with the elbow filled with a sodium tungstate solution, a variation in the internal dimension was indicated across the width of the bend. Corrections were applied to the relative count rates in this case, using thickness correction factors obtained from the traverses with the sodium tungstate solution in the bend.

In general, traverses were taken across the pipe and back for each flow setting, to ensure the concentration was not changing with time. Runs in which concentration did change with time were rejected.

TABLE II

System	Test pipe	V_m ft/sec	V_s ft/sec	D ft	$D^{2.2} \times [(\rho_s - \rho_l)/\rho_l]^{2.2}$
Talc-water $(\rho_s-\rho_l)/\rho_l = 1.7$	$\frac{3}{4}$ in.	1.37	1.17	0.063	0.67
	1 in.	1.42	1.21	0.084	0.71
	1½ in.	1.45	1.30	0.125	0.77
	2 in.	1.62	1.37	0.167	0.82
Barium sulphate-water $(\rho_s-\rho_l)/\rho_l = 3.5$	$\frac{3}{4}$ in.	1.55	1.43	0.063	0.84
	1 in.	1.56	1.39	0.084	0.89
	1½ in.	1.85	1.62	0.125	0.96
	2 in.	1.97	1.73	0.167	1.02
Red lead-water $(\rho_s-\rho_l)/\rho_l = 8.1$	$\frac{3}{4}$ in.	2.04	1.74	0.063	1.08
	1 in.	2.20	1.93	0.084	1.14
	1½ in.	2.47	2.38	0.125	1.24
	2 in.	2.57	2.43	0.167	1.31
HRI tungsten-water $(\rho_s-\rho_l)/\rho_l = 18.3$	1 in.	—	2.62	0.083	1.45
BHP tungsten-water $(\rho_s-\rho_l)/\rho_l = 18.3$	$\frac{3}{4}$ in.	—	2.54	0.063	1.38
	1 in.	—	2.75	0.084	1.46
	1½ in.	3.06	3.00	0.125	1.58
	2 in.	3.17	3.09	0.167	1.67
UO_2-NaK 25°C[15] $(\rho_s-\rho_l)/\rho_l = 11.5$	0.437 in.	2.1		0.036	1.07
UO_2-NaK 450°C[15] $(\rho_s-\rho_l)/\rho_l = 13.2$	0.437 in.	2.4		0.036	1.12
Lime-water[14] 10 per cent $(\rho_s-\rho_l)/\rho_l = 1.0$	10.2 cm	0.90		0.334	0.80

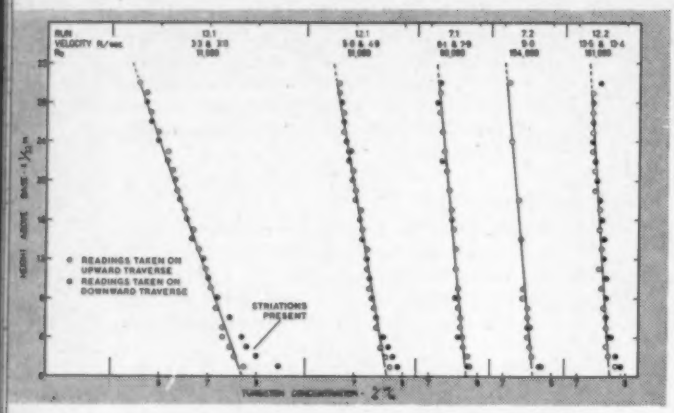

Fig. 6. Concentration measurement across horizontal pipe using thulium 170.

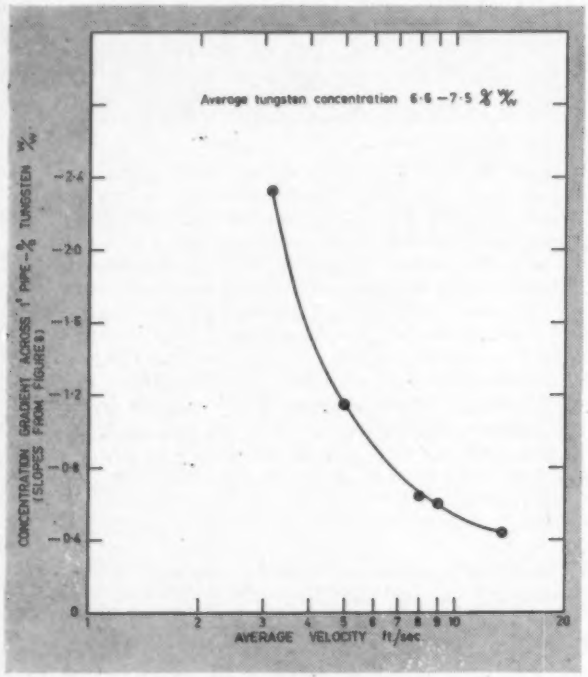
Average tungsten concentration 6·6 – 7·5 % w/w
CONCENTRATION GRADIENT ACROSS 1" PIPE – % TUNGSTEN w/w (SLOPES FROM FIGURE 6)
AVERAGE VELOCITY ft/sec

Fig. 7. Concentration gradients in horizontal pipe.

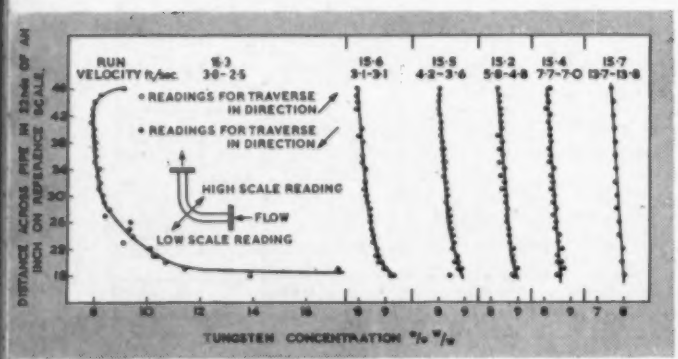

Fig. 8. Traverses across centre of 90° elbow

Horizontal Pipe

Fig. 6 shows the results obtained plotted as distance from the bottom of the pipe versus per cent tungsten. The velocities shown are those measured before and after the run.

As the presence of dissolved tungsten can be critical, this was determined by analysis before and after each set of readings. The concentration of tungsten present in solution was less than 0.1 per cent, which was neglected.

With increasing velocity, it is to be expected that the suspension would be more uniform, and this is shown by the increasing negative slopes in Fig. 6, where the mean velocity varies from 3.2 to 13.4 ft/sec. Using the density and viscosity[22] of the suspension, the mean Reynolds numbers for these runs varied from 31,000 to 161,000. If the Reynolds number of a suspension is an indication of turbulence, it is surprising that these conditions did not give uniform mixing. The negative slope for run 12.2 in Fig. 6 corresponds to a decrease of approximately 0.5 per cent by weight in the suspended tungsten present from the bottom to the top of the pipe. This is equivalent to a change of approximately 6 per cent in the concentration of tungsten across the pipe section.

Plotting the slopes from Fig. 6 versus velocity on semi-log paper, as in Fig. 7, indicates that velocities very much greater than 13.4 ft/sec ($Re > 161,000$) are needed to produce a uniform suspension in horizontal flow. This is further evidence that the minimum Reynolds number of 2000-3000 accepted by other workers[6, 7] for "homogeneous" transport of sub-sieve sized particles in horizontal flow is incorrect. It was not possible to determine the limiting velocity at which complete uniformity of suspension is obtained.

The deviation of the points of run 13.1 in Fig. 6 on the downward traverse is due to the decrease in velocity encountered during this run, 3.3 to 3.0 ft/sec. At 3.0 ft/sec very heavy striations were evident and a bed had almost formed.

It was noticed that the results for the beam just above the bottom of the pipe were consistently high. This may have been due to tungsten particles depositing in the internal crevices between adjacent walls of the perspex pipe, causing a slight build-up of particles in the lower corners.

Furthermore, readings close to the pipe walls at both the top and bottom of the pipe are less reliable, because a small error in alignment would have caused part of the beam to travel through the perspex.

When the flow rate of the suspension was decreased from that for the fully suspended state, striations appeared on the bottom of the pipe as the horizontal settling velocity was approached. These striations, which have been observed in previous work,[5] are longitudinal bands of higher particle concentration than the surrounding suspension. They were most noticeable at velocities just above the settling velocity, and were observed only on the base of the square pipe. Striations are apparently narrow moving beds with velocities much less than the main stream velocity. Turbulence in the main stream is sufficient to prevent an even bed forming, although the explanation for line formation is unknown.

At the same time "negative" striations were observed at the top of the pipe. These are longitudinal bands of lower particle concentration than the surrounding suspension. No striations were observed through the vertical walls, but lines much less pronounced were visible.

90° Smooth Elbow

The results for the traverse of the elbow are given in Fig. 8, which shows the variation in tungsten concentration for six different loop velocities. The velocities shown in Fig. 8 are those measured before and after each run. The concentration of dissolved tungsten present in the water

during these experiments was less than 0.02 per cent.

The flattening of the concentration profiles with increase in velocity is consistent with results on concentration gradients in a horizontal pipe. It is also apparent that very large differences in concentration exist, particularly at low velocities at the cross-section traversed. Fig. 8 shows that uniform suspension is not obtained at the centre of the elbow even at the highest velocity used.

Vertical Pipe

The concentrations indicated for the vertical pipe were all very similar, and it was not necessary to evaluate actual tungsten concentrations. For comparison purposes, and in order to determine whether suspension is uniform or not for the full length of the vertical pipe, the results have been presented in terms of the relative count rate N/N_A. These when plotted have the same shape, although inverted, as concentration profiles.

For all the vertical pipe runs, two velocities were used; a low velocity corresponding to a flow rate just above the horizontal settling velocity, as indicated by visual observation of very heavy striations; and a high velocity corresponding to a flow rate with the by-pass shut and loop valve full open. From previous runs, these correspond to average velocities of approximately 3 and 13.5 ft/sec respectively.

The results are plotted in Figs. 9 and 10. It is apparent that the concentration profiles flatten as the suspension travels up the pipe which indicates that mixing is taking place along the pipe.

It appears that the flattening of the profiles is due to the gradients established in the horizontal section being destroyed, and that considerable distance is needed to achieve this after a smooth elbow. For velocities of approximately 3 and 13.5 ft/sec, this distance is about 4 ft from the start of the straight vertical pipe, assuming that uniformity is achieved when relative count rates across the pipe are consistent to ± 0.5 per cent. Insufficient turbulence is present, even at the highest velocity used, to provide immediate mixing after the bend. This supports the previous conclusion that the Reynolds number of a suspension is not a measure of turbulence or particle suspension.

There was no visual evidence of "coring"[11] for the flow conditions encountered, and, indeed, in Figs. 9 and 10 it is seen that the concentration is always either uniform or slightly lower at the centre. The lower concentration at the centre of the pipe is difficult to explain satisfactorily in the absence of velocity profile measurements.

Conclusions

It may be concluded that:

(a) For dilute sub-sieve particle suspensions flowing in a horizontal pipe, a moving bed is usually obtained before a stationary bed is formed, as the velocity is reduced.

(b) Striations have been observed in all suspensions studied at velocities near the horizontal settling velocity.

(c) For dilute sub-sieve particle suspensions with concentrations up to several per cent by volume, the horizontal settling velocities are almost independent of the concentration circulating.

(d) The data from this investigation and the literature on the horizontal settling velocity may be correlated empirically in terms of the pipe diameter and the effective density ratio.

(e) A dimensionless correlation for horizontal settling velocities has been obtained for particles between 242 and 380 microns, which is an improvement on the existing equation.[14]

(f) A generalised correlation of horizontal settling velocities for all particle sizes in terms of dimensionless groups is not possible until some method is available for determining the effective or "working" diameter of suspended

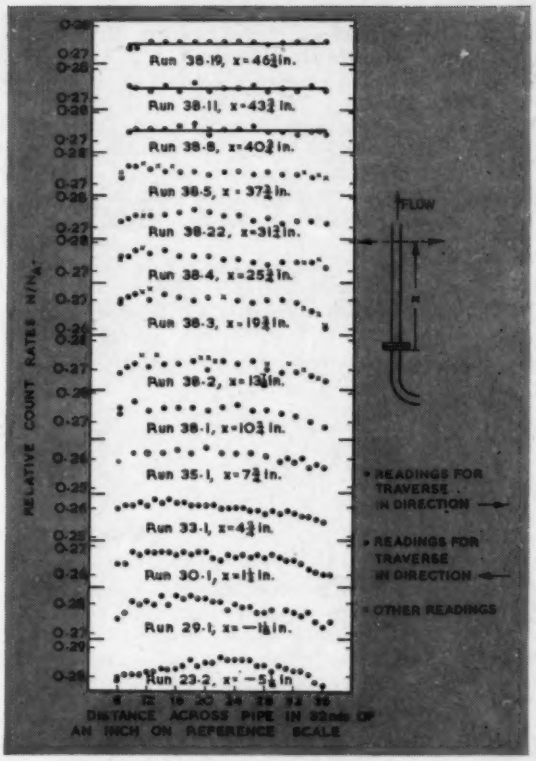
Run 38-19, x=46½in.
Run 38-11, x=43⅜ in.
Run 38-8, x=40¼ in.
Run 38-5, x=37⅛ in.
Run 38-22, x=31⅛in.
Run 38-4, x=25⅛ in.
Run 38-3, x=19⅛ in.
Run 38-2, x=13⅛in.
Run 38-1, x=10⅜ in.
Run 35-1, x=7⅜ in.
Run 33-1, x=4⅜ in.
Run 30-1, x=1⅛ in.
Run 29-1, x=−1⅛ in.
Run 23-2, x=−5⅛ in.
RELATIVE COUNT RATES N/N_A
FLOW
• READINGS FOR TRAVERSE IN DIRECTION
• READINGS FOR TRAVERSE IN DIRECTION
• OTHER READINGS
DISTANCE ACROSS PIPE IN 32nds OF AN INCH ON REFERENCE SCALE

Fig. 9. Traverses on vertical pipe for low velocity of suspension (~3 ft/sec).

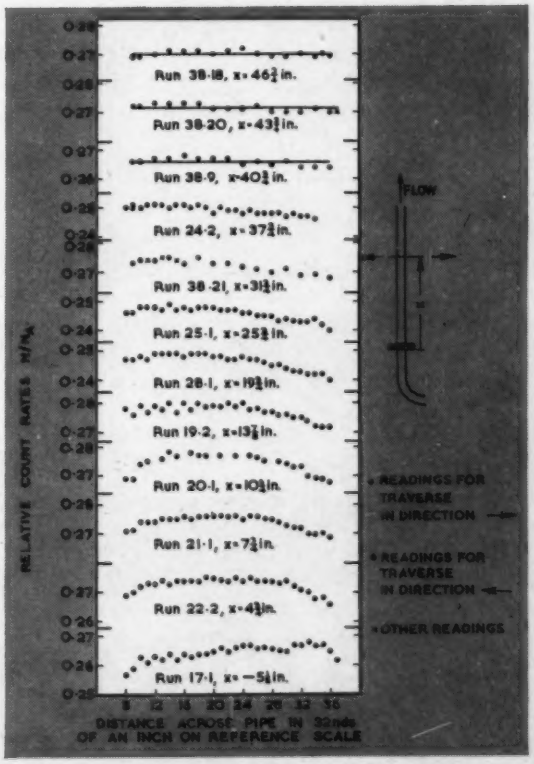

Fig. 10. Traverses on vertical pipe for high velocity of suspension (~13.5 ft/sec).

sub-sieve particles having a significant size distribution.

(g) Velocities much greater than 13.4 ft/sec ($Re > 161,000$) are needed to produce uniform and homogeneous suspension of the tungsten powder suspension used in horizontal flow in a 1-in. square pipe.

(h) Large differences in concentrations exist at a smooth elbow, and uniform mixing was not obtained at the highest velocity used of 13.8 ft/sec.

(i) Velocities up to approximately 13.5 ft/sec have a negligible influence on the degree of mixing in upwards flow from the horizontal to vertical positions. A vertical distance of approximately 4 ft is required before the suspension can be considered uniform.

(j) The bulk Reynolds number of the suspensions used is not a measure of turbulence, or degree of suspension.

(k) No evidence of "coring" was found in this work.

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REFERENCES

[1] Alder, K. F., *Australian Atomic Energy Symposium*, 1958, 346.
[2] Cairns, R. C., and Turner, K. S., A.A.E.C. Report E5, 1957.
[3] Cairns, R. C., and Turner, K. S., A.A.E.C. Report E16, 1958.
[4] Cairns, R. C., A.A.E.C. Report E17, 1958.
[5] Cairns, R. C., *Second United Nations International Conference on the Peaceful Uses of Atomic Energy*, 1958, **7**, Paper 1092.
[6] Newitt, D. M., Richardson, J. F., Abbott, M., and Turtle, R. B., *Trans. Instn. Chem. Engrs.*, 1955, **33**, 93.
[7] Durand, R., and Condolios, E., *Proceedings of a Colloquium on the Hydraulic Transport of Coal held by the National Coal Board, London*, 1952, 39.
[8] Rouse, H., *Fluid Mechanics for Hydraulic Engineers*, 1st ed., McGraw-Hill Book Co. Inc., New York, 1938.
[9] Prandtl, L., *Essentials of Fluid Dynamics*, Blackie & Son Ltd., London, 1952.
[10] Ismail, H. M., *Proc. Am. Soc. Civil Engrs.*, 1951, **77**, Separate No. 56.
[11] Wolfe, H. E., and Murphy, G., U.S.A.E.C. Report ISC-874, 1957.
[12] Cairns, R. C., and Turner, K. S., A.A.E.C. Report E34, 1958.
[13] Abraham, B. M., Flotow, H. E., and Carlson, R. D., *Advances in Nuclear Engineering*, Pergamon Press, London, 1957, **2**, 473.
[14] Spells, K. E., *Trans. Instn. Chem. Engrs.*, 1955, **33**, 79.
[15] Settle, J. J., *Private Communication*, September, 1958.
[16] Turner, K. S., M.Sc. Thesis, University of N.S.W., Sydney, 1959.
[17] Dallavalle, J. M., McBride, J. P., Allred, V. D., and Jones, E. V., U.S.A.E.C. Report ORNL-2565, 1958.
[18] Watt, J. S., and Lawther, K. R., *Australian Atomic Energy Symposium*, 1958, 610.
[19] Cairns, R. C., and Lawther, K. R., A.A.E.C. Report E37, 1958.
[20] Cairns, R. C., and Lawther, K. R., A.A.E.C. Report E38, 1958.
[21] Orr, C., and Dallavalle, J. M., *Chem. Eng. Progr. Symposium Series No. 9*, 1954, **50**, 29.

Progress at Carrington

EVIDENCE of the post-war boom in Britain's chemical industry was to be seen at the Carrington works of the Shell Chemical Co. when the works were thrown open to the Press for the first time recently. This plant, acquired by Shell in 1955, was originally erected by Petrochemicals Ltd. in the immediate post-war period. It occupies an 850-acre site, of which about 250 acres are so far developed. Provision is made for eventual expansion up to about 650 acres. The naphtha feedstocks required for all the chemical operations are pumped through an underground pipeline system from the Shell refinery at Stanlow, 23 miles away.

The use of automatic control of processes and central control rooms are one of the features of the plant. The extensive new control room in the Ethylene II unit (illustrated) is one of the largest in Europe, and as new processes are planned, automation will play a bigger and bigger part.

One of the newer plants at the works is the styrene monomer plant. This monomer, manufactured from ethylene and benzene produced on the site, is used in the production of polystyrene moulding materials.

The plant produces a wide range of polystyrenes with different grades for different applications, ranging from basic, general-purpose grades to toughened and heat-resistant materials. Various additives or colour pigments can be mixed in. The polymer is produced in the form of long strands which are cooled and chopped into granules ready for sale to the moulding firms. Polystyrene has a host of applications for making such things as refrigerator linings and components, television and radio cabinets, car fittings, domestic ware and toys.

A novel form of this material is the expanded or foamed polystyrene known as "Styrocell". Gassing agents used under controlled conditions blow up the plastic, which is then formed into very light expanded board sixty times as light as water. The ease with which even large slabs of this material may be handled is illustrated in the picture. The board can be used for insulation in cold rooms and domestic buildings and a large market exists in chemical plants where lagging is required to preserve low temperatures. It can be useful too for packaging expensive delicate instruments.

The ever-increasing demands made on our chemical industry for new, cheaper and better materials for a multitude of uses call for more and more production plant to be made available. To meet this need the Shell company are planning vast new expansions to their plastics and synthetic rubber operations. Work is due to start next year on a big synthetic rubber plant which is expected to be operational by 1963 for the manufacture of polybutadiene/polyisoprene rubber. A new plant for the manufacture of low density polyethylene by the high pressure process is currently under construction.

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THE PERFORMANCE OF A GRAVITY-FEED CLIMBING FILM EVAPORATOR

by J. C. R. TURNER, M.A., Ph.D.

IN a recent paper, DOLL-STEINBERG[1] has described work carried out by DOLL-STEINBERG and MORRIS[2] on a climbing film evaporator. This work has been continued by BLAKER and DE VERTEUIL[3] and by FLEMING and MATTHEWS,[4] and is described below.

The apparatus remained basically that described by DOLL-STEINBERG, and is shown diagrammatically in Fig. 1. It consisted of a steam-jacketed evaporator tube supplied with a feed of distilled water via a tank connected to a constant-head. A pump circulated water to the tank from an open reservoir, to which the overflow from the constant-head tube returned. This water was kept at near its boiling point by live steam injection. Electric heating coils were fitted in the tank below the evaporator tube and the water in this tank was kept as close as possible to the boiling-point at atmospheric pressure by adjusting the current through these coils with a rheostat.

With the constant-head tube adjusted to give the desired immersion, steam was passed into the jacket surrounding the evaporator tube. Boiling took place in the tube and a two-phase mixture issued from the top. This was separated at atmospheric pressure in a vessel surrounded by an atmospheric pressure steam jacket. The water flowed through a system of measuring cylinders back to the open reservoir. The steam passed to a condenser, and the condensate returned through a similar measuring system to the reservoir.

When steady conditions prevailed, the following variables were recorded:

(1) the height of the constant-head tube;
(2) the evaporator tube steam jacket temperature and pressure;
(3) the temperatures of the closed tank and separator jacket; and
(4) the water and steam rates.

An important modification was made in the separator design. That used by DOLL-STEINBERG and also a later model were both found to be incapable of preventing serious entrainment at the highest water rates observed. Finally, a disc-and-doughnut separator was designed. Each of the two discs and doughnuts was provided with a liquid downcomer to drain the water collecting on it. The separator was about 6 in. high and 3 in. in diameter. With up to 700 lb of water per hour emerging from the evaporator, the separator did not flood and the condensed steam contained less than 1 per cent of its volume of water entrained from the separator. This was determined by evaporating a solution of fluorescein and testing the condensate colorimetrically. The results of the earlier investigators using less efficient separators are regarded as inaccurate at high flow rates.

Symbols Used

$\triangle\theta$ = overall temperature difference, °F. (Heating steam temperature) − (Atmospheric b.p. of water);
h = overall heat transfer coefficient, based on internal tube area, Btu hr^{-1} ft^{-2} $°F^{-1}$;
s = steam rate, lb/hr;
λ = latent heat of evaporation, Btu/lb; and
A = internal area of tube, sq ft.

TABLE I

Tube	Material	Length, ft	I.D., in.	O.D., in.
A1	Copper	4.30	0.354	0.496
A2	"	2.80	"	"
A3	"	1.43	"	"
B1	Brass	4.30	0.669	0.748
B2	"	2.80	"	"
B3	"	1.43	"	"

Oscillations in the constant-head and stand pipes often occurred, most noticeably with high heating temperatures. The water rates were of poor reproducibility and appeared to be markedly affected by these oscillations, as well as by small (0.2°F) variations in the tank temperature. The steam rates were of good reproducibility and were unaffected by both oscillations in the constant-head and small variations in the tank temperature.

A copper tube and a brass tube were used, both with unpolished surfaces. After use the inner surfaces of the tubes were found to be considerably roughened over the centre third of their length. In view of the importance of surface conditions in nucleate boiling (which may, in fact, have caused the observed roughening), it should be borne in mind that results from one tube can only with caution be used to predict the behaviour of others.

The condition of the outer-heating-side surface of the tube is also important. In practice, condensing steam is often used as the heating medium and the resistance to heat transfer of the condensate layer is not always negligible in comparison with the resistance to heat transfer on the inner surface of the tube. The conditions of this surface will determine whether condensation is drop-wise or film, and the thickness of the film will vary down the tube. It is also necessary to ensure that inerts are purged from the heating medium or the tube will rapidly become "blanketed".

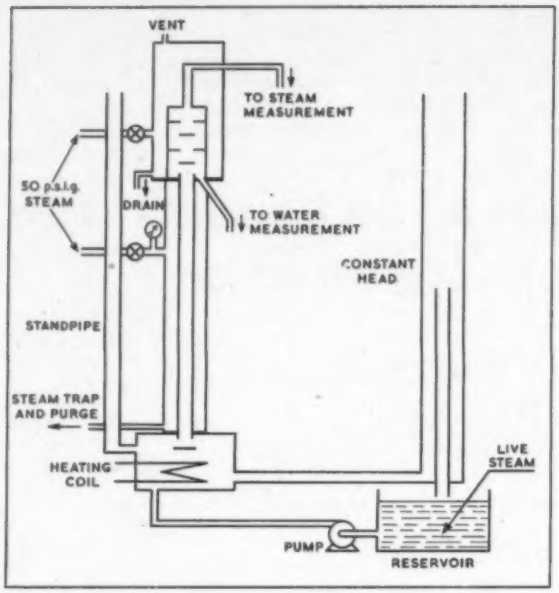

Fig. 1. Electrically-heated, steam-jacketed, single-tube, climbing-film evaporator used in the research.

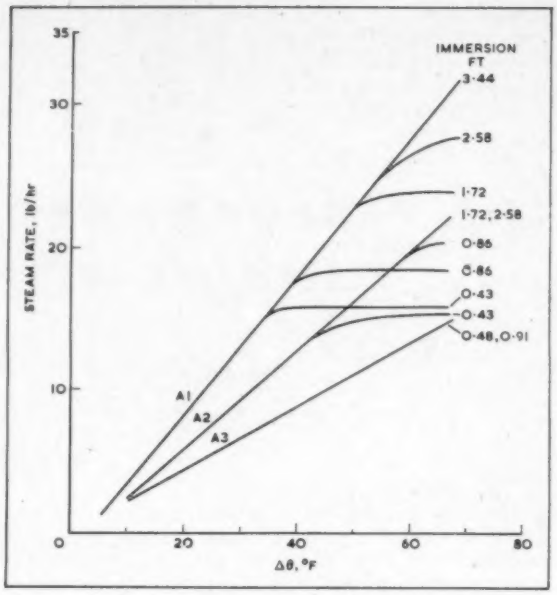

Fig. 2. Steam rate v. overall temperature difference for 0.354-in. I.D. tubes at various immersions.

In our experiments this purging was carried out at frequent intervals.

Attempts were made by the first two pairs of workers to measure the temperature of the tube wall at various points along its length. This was done by soldering thermocouples to the tube. The temperature measured showed variations along the tube, but unfortunately these variations made little sense. The superposition of a soldered pair of wires on a thin-walled tube alters the heat flow in this region radically. The thermocouple thus records a temperature between that of the steam and the inner surface of the tube, but the exact point between depends upon the soldered junction and the thickness of the condensate layer in its neighbourhood. By using an evaporator tube of copper and spotwelding constantan wires to points along its length some improvement was effected, but not sufficient to justify calculations involving tube wall temperatures.

Table I shows the tubes used in this investigation.

In Figs. 2 and 3 the steam rate is plotted against the overall temperature difference, $\triangle\theta$, for the various tubes. The immersions are the apparent static head of water above the tube base as indicated by the constant-head level.

With the smaller tube, "drying out" occurred at higher $\triangle\theta$ for the two greater lengths (A1, A2) but not for the shortest length (A3). With the larger tube "drying-out" occurred only at the lowest immersion of the greatest

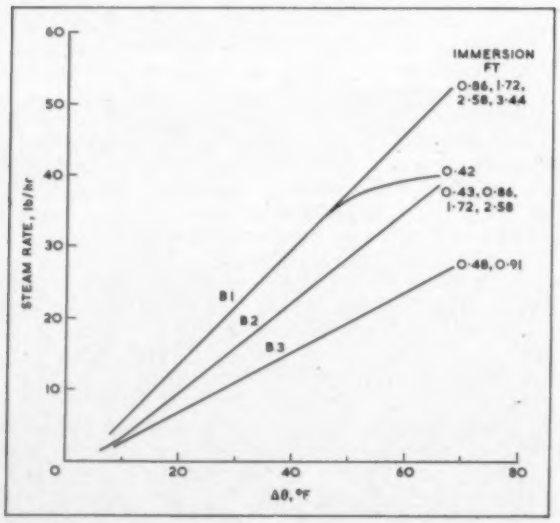

Fig. 3. Steam rate v. overall temperature difference for 0.669-in. I.D. tubes at various immersions.

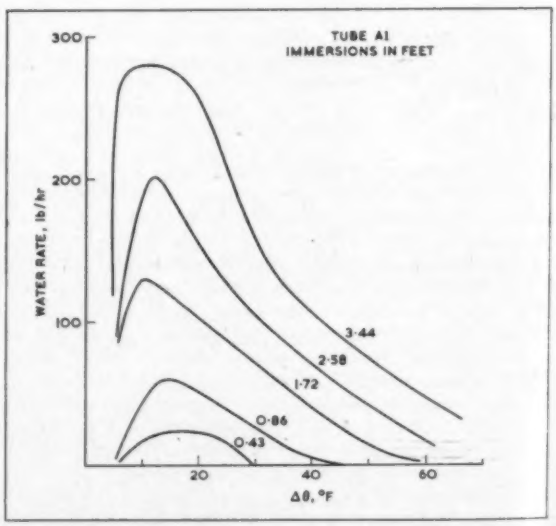

Fig. 4. Water rate v. overall t.d. for 0.354-in. I.D. tube 4.3 ft long at various immersions.

length tube (B1). The use of higher values of $\triangle\theta$ than were possible in this investigation would reveal "drying-out" in higher immersion or shorter length cases.

The immersion had no effect upon the *steam* rate as long as "drying-out" did not occur (but see the *water* rate curves, Fig. 4). As far as the experimental scatter allows, it appears that the steam production varied linearly with $\triangle\theta$ for $\triangle\theta > 10°F$. This line extrapolates back to zero steam production at $\triangle\theta = 2°\text{-}5°F$. In the region $\triangle\theta < 10°F$ it was difficult to make measurements of the reliability necessary to demonstrate the relationship $h \propto \triangle\theta^{0.3}$ proposed by DOLL-STEINBERG; and no convincing evidence has been obtained of this relationship in any of the work done in this department. That is not to say that in a similar apparatus designed to work at low values of $\triangle\theta$ such a relationship may not be demonstrated.

The amount of steam produced by a tube which was showing "drying-out" was approximately independent of the length of tube above the wet zone, as one would expect. Further heat transfer, which was small, only served to superheat the steam. This can be seen by referring to the 0.43 ft and 0.86 ft immersions of tubes A1 and A2 in Fig. 2. Experiments at higher $\triangle\theta$ would show whether this proposition is more generally true.

Water circulation at varying $\triangle\theta$ is shown for Tube A1 in Fig. 4. The other tubes showed the same general characteristics. The water circulation went through a maximum at a low value of $\triangle\theta$ (about 15°-25°F). The higher the immersion, the greater was the value of the maximum and the more peaked its shape. For the tubes B1, 2, 3 the maximum at highest immersion rose to 950 lb./hr. These curves, which are very similar to those presented by DOLL-STEINBERG, can be only roughly divided into three regions. With increasing $\triangle\theta$ the water circulation at first increases as the small bubbles of steam in the two-phase mixture increase in number and size. The resultant lowering of the density causes an increased circulation. When the bubbles become larger and start to amalgamate (at higher $\triangle\theta$) slip between the vapour and the liquid occurs and less water is driven over. As $\triangle\theta$ increases further, the tube wall may dry out at the top of the tube, while the core of vapour still contains a small amount of liquid entrained from below. However, at the lowest immersions and highest $\triangle\theta$ the amount of water coming out of the top of the tube is reduced to negligible proportions.

The overall heat transfer coefficient h is given by

$$h = s\lambda / A\triangle\theta$$

since the liquid feed to the tube was at its boiling point at atmospheric pressure. The value of λ is a constant since the separator was always at atmospheric pressure. Hence h is easily calculated from the graphs shown in Figs. 2 and 3, and plots of h against $\triangle\theta$ are given in Figs. 5 and 6.

It is clear from the s v. $\triangle\theta$ graphs that h will increase with $\triangle\theta$ at first. The fact that the s v. $\triangle\theta$ straight lines extrapolate to a point not far from the origin means that h tends fairly rapidly to a nearly constant value, only falling sharply when "drying-out" occurs. The effect of varying the immersion is only to vary the point at which "drying-out" does occur.

For both tubes A and B, increasing the length of the tube reduces h at any given $\triangle\theta$. There may be "entry length" properties giving rise to good heat transfer; for instance, the fluid close to the tube wall is rapidly superheated in the entry length. However, the average heating side resistance will also increase with tube length as the average thickness of the condensate film increases, and the observed fall in h with increasing length may be due to this cause. For tubes of the same length but different diameter, there is practically no difference in the value of h obtained, except at low values of $\triangle\theta$.

The absence of any effect on h due to varying immersion or water circulation leads to the conclusion that whether gravity feed or forced feed is used will have little effect on the heat transfer performance of an evaporator provided that the water circulation is sufficient to keep the tube wet. However, the mode of heating the tube (forced fluid convection, condensing steam or electrical heating) and the surface conditions are important factors to be considered when comparing the behaviour of different evaporators working with the same fluid.

REFERENCES

[1] DOLL-STEINBERG, *Brit. Chem. Eng.*, 1958, **3**, 536.
[2] DOLL-STEINBERG and MORRIS, Project Report 1956, Department of Chemical Engineering, Cambridge University.
[3] BLAKER and DE VERTEUIL, Project Report 1957.
[4] FLEMING and MATTHEWS, Project Report 1958.

ACKNOWLEDGMENTS

The author thanks G. E. BLAKER, R. G. FLEMING and R. N. MATTHEWS for their helpful comments and for permission to use information given in their reports.

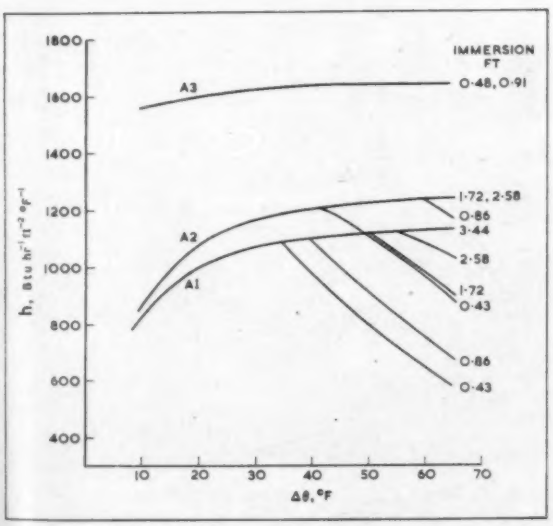

Fig. 5. Overall heat transfer coefficient (based on internal area) v. overall t.d. for 0.354-in. I.D. tubes.

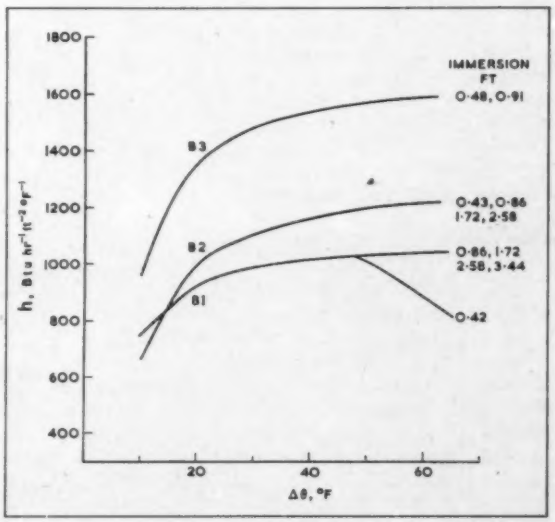

Fig. 6. Overall heat transfer coefficient (based on internal area) v. overall t.d. 0.669-in. tubes.

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DEVELOPMENTS IN THE EXTRACTION OF SUGARCANE WAX

An application of the principles of filtration-extraction to the production of sugarcane wax from sugarcane

by J. POMINSKI and B. M. KOPACZ*

BECAUSE the United States is dependent on foreign sources for almost all of the plant waxes of commerce, as shown by Table I, research is being carried out to establish domestic sources of wax offering promise of reducing this dependence.

Wax users in the U.S.A. have long desired a domestic supply of waxes that can replace or supplement the high-priced *carnauba* and other imported waxes such as *curicuri* and *candelilla*. Some research work has been reported on potential domestic sources such as rice bran,[12, 19, 20] the bark of fir trees[16] and jojoba seed.[3, 15] New process developments make possible the recovery of rice wax, but the potentially available wax from the total rice bran available in the U.S.A. is only a fraction of the present-day needs. The recovery of wax from fir trees involves not only an extraction process, but also additional processing to produce wax-like material of suitable quality. U.S. sugarcane is a potential source of about 7 million lb of crude wax, which after refining yields approximately 60% hard wax.[2]

In the milling of sugarcane many of the lipids present in the cane are dispersed in the juice, the wax mainly in coarse agglomerates (c.a. 200 mesh). Ordinary lime clarification as employed in Louisiana removes a large part of the lipids and quite efficiently removes the wax.

All of the sugarcane wax currently used in the United States is imported from Cuba as crude wax. This product is solvent fractionated and refined at a plant in Gramercy, Louisiana.[23, 25, 26, 27] The product from this plant finds principal application in carbon paper. Shoe polishes, floor waxes, printing inks and finishing materials are other minor uses.

Composition of Sugarcane Wax

As early as 1840 Avequin[1] recognised that the whitish coating on the stalks of sugarcane was a type of wax to which he gave the name *Cerosin*.

Early investigators—Dumas[7] in 1841 and Lewy[17] in 1845—were of the opinion that the wax consisted of a single, high molecular weight alcohol. Later investigators have established that *Cerosin*, like many other natural waxes, is a mixture of esters, acids, alcohols and other hydrocarbons. To date, the individual constituents of sugarcane wax in

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TABLE I—Waxes Imported into United States (1953–57)

Wax	5-year average imports (mil. lb)	Price range ($/lb)
Carnauba	17.0	0.56–1.45
Candelilla	2.9	0.52–0.78
Curicuri	1.6	0.65–1.15
Sperm Whale Oil	30.1	0.10–0.175
Miscellaneous*	2.8	

* Japan wax and vegetable waxes not specified.

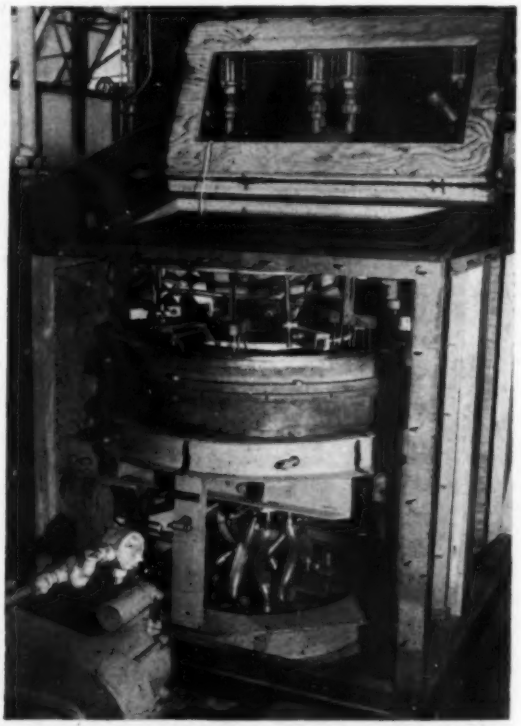

Fig. 1. Small-scale, horizontal, rotary vacuum filter (3-ft diameter) used in USDA pilot-plant work.

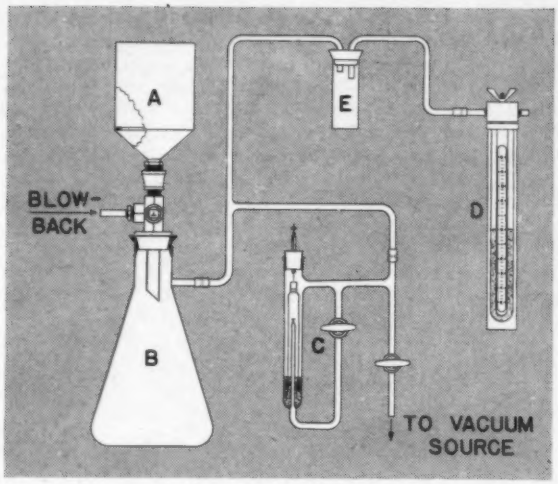

Fig. 2. Bench-scale equipment. A—stainless-steel filter funnel, 5¼ in. diameter; B—4000-ml. suction flask; C—Cartesian monostat; D—monometer; E—mercury trap.

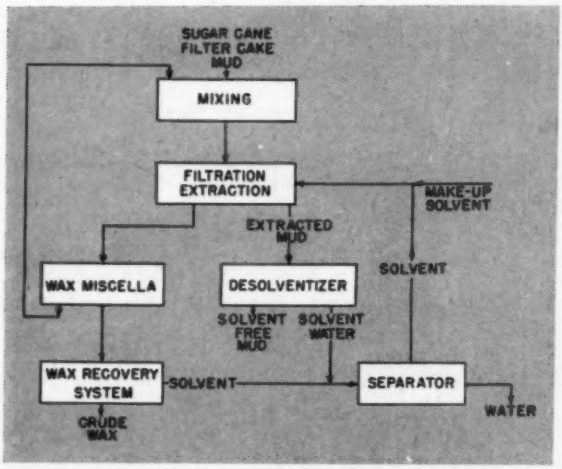

Fig. 3. Flow diagram for the filtration-extraction of sugarcane mud to produce crude wax.

TABLE II—Data on Refined Sugarcane Wax[14]

Source	Melting point	Sp. gr.	Saponification value	Acid value	Iodine value	Acetyl value
Louisiana	78–80	0.99–1.00	51.9–57.0	13–15.6	8–13.3	71.1
Commercial	79–81	—	65–77	23–28	—	—
Cuticle wax	74–77	—	34.0–56.7	15.6–23.8	—	—

TABLE III—Comparison of Mill Processing in Cuba and in Louisiana

Mill	Best year	Tons processed	Days operated
Sterling (La.)	1956	192,400	61
Raceland (La.)	1955	255,515	76
Evan Hall (La.)	1955	279,000	69
Chaparra (Cuba)	1952	1,235,000	204
Delicias (Cuba)	1952	1,850,000	206
Chaparra (Cuba)	1955*	633,000	86
Delicias (Cuba)	1955*	900,000	99

* Under restrictions.

their natural forms have not been completely identified. Table II gives some typical characteristics of refined sugarcane wax and cuticle wax.

Unfortunately, most of the data to be found in the literature on sugarcane wax refers to crude wax and not to fully refined wax, consequently the composition varies widely. For example, melting points from 76 to 84°C have been reported. Probably much of this variation is due to the manner in which the wax was obtained and purified.

True sugarcane wax is sparingly soluble at ordinary temperatures in all of the so-called wax solvents,[14] but at temperatures above the melting point of the wax it becomes soluble in many of them in all proportions.

Extraction of Crude Wax

Sugarcane wax was commercially extracted for the first time in Natal, South Africa, during the First World War. The plant operated for a number of years, producing large quantities of wax. It is reported that as much as 12 million lb were exported in 1924. The failure of the Natal operation is generally attributed to the production of a poor quality and non-uniform crude product. It is now known that it is particularly important during the production of the crude and the separation of the wax to avoid the occurrence of undesirable reactions in the oil and resin fractions.[18]

Currently in Cuba the sugarcane mud from the clarification is subjected to a continuous countercurrent solvent extraction using heptane as the solvent.[22] The daily capacity of one such installation in 1947 was approximately 10,000 lb of crude wax. The system used consists of a vertical type extractor into which is fed the wet mud (60-85% water) and solvent.[18]

The present method of obtaining crude sugarcane wax in Cuba (the Swenson process) is not considered satisfactory for application to U.S. sugarcane from the standpoint of economics. Wax recovery, solvent losses, length of grinding season, size of crop, and particularly the lower wax content of domestic U.S. sugarcane, militate against large central installations in Louisiana. Cuban mud usually contains 12-14% wax while Louisiana mud normally contains about 7% wax. Table III shows that some Cuban sugar mills, even under restrictions as in 1956, processed much larger quantities of cane than did the Louisiana mills. Not enough sugarcane mud is produced at any one Louisiana mill to warrant a wax-extracting installation of the type used in Cuba in conjunction with large mills such as Chaparra or Delicias. Thus, it would be necessary to haul the mud to a centrally located plant which would be more uneconomical because of transportation and storage costs. In addition, higher processing costs could be expected because of the lower wax content of Louisiana mud. Such a plant would require heavy capitalisation for use only during the short milling season and to process only one commodity—sugarcane mud.

These limitations of the Swenson process when applied for use on the small-scale production indicated for even the larger Louisiana mills led ARS engineers to adapt the more versatile filtration-extraction method to extract wax from sugarcane mud.[21]

If the process could be applied to the extraction of wax from sugarcane mud during the interval when oilseed processing was not in progress, as, for example, peanuts, sesame, safflower or rice bran, the capital cost of the installation could be more easily justified even though storage and hauling costs would necessarily be incurred.

Filtration-extraction

Filtration-extraction is a solvent extraction process[4, 5, 6, 8, 12, 13] that can handle oilseeds and materials of widely varying oil or wax content and has given small and medium size mills a means of lowering operating costs and increasing yields. Several features interest small mills in the Southern

U.S. which are faced eventually with the problem of econonomically processing more than one material in a season. The process requires a low ratio of solvent to the material being extracted and permits the use of smaller solvent equipment than with conventional processes. It was first applied successfully to commercial production of oil and meal from cottonseed and soyabeans. It is also suitable for peanuts, flaxseed, sesame, castor beans and rice bran. The sugarcane wax application is the result of continuing research to adapt the filtration-extraction to the processing of other materials.

Bench-scale apparatus and procedures devised during the development of the process for cottonseed,[5, 24] soyabeans[4, 9] and rice bran[12, 19, 20] are presently being used in the refinement of the process for these materials as well as the development of the process for other oil- and wax-bearing materials such as jojoba and sugarcane mud.

These procedures and equipment permit the prediction with a fair degree of accuracy of the performance of large continuous horizontal filters.[11] Data can be determined with a few pounds of material and extrapolated to commercial size operation.

The Louisiana sugarcane mud used contained (on a dry basis) about 7% crude wax. Heptane was used as the extraction solvent. A slow-speed planetary-type paddle mixer was used in slurrying materials prior to extraction. High-speed vane-type mixers[10] were not satisfactory. A bench-scale filtration-extraction apparatus[11] with a removable screen was employed to evaluate the filtration-extraction characteristics of the heptane-sugarcane and slurries.

Conditions for Efficient Wax Recovery

Wet sugarcane mud was slurried with hot heptane and the resulting mixtures subjected to bench-scale filtration-extraction tests, to determine conditions for obtaining efficient removal and recovery of wax. Wet sugarcane muds, unlike vegetable oilseeds, need no additional conditioning, such as comminution, cooking and reforming, prior to extraction. Several groups of experiments were conducted, but only pertinent and promising data are shown in Table IV.

TABLE IV—Filtration-Extraction Data*

Sample: (a) Preparation	None
(b) H_2O, %	70
Mass velocity, lb/hr/sq.ft	5725
Extractables in cake, %	1.1
Extracting efficiency, %	85.0

* Extracting conditions were as follows: weight of sugarcane mud—530 g.; planetary type mixing; extracting temperature—170°F.; number of heptane washes—3; solvent to mud ratio—1 to 1; filter screen—60 × 60 mesh; cake thickness—2 in.; vacuum during filtration—4 in. Hg.

The "as is" sugarcane mud was slurried with heptane at 170°F for 1 hr except for the first group of experiments, where time was varied from ½ to 2 hr. The mixtures were extracted by filtration so that mass velocities were obtained on a 2-in. thick cake at a vacuum of 4 in. of mercury. Mass velocity is defined as pounds of miscella (solvent and wax) filtered per hour per square foot of filter area and a value of 2000 or better is considered satisfactory for practical commercial use. Residual lipids were determined on the extracted material.

The "as is" materials gave high mass velocities and a high extraction efficiency of 85.0%, while the addition of moisture to the mud decreased the extraction efficiency considerably. In addition, increasing the moisture lowered the mass velocity from a high 5700 to an impractical low rate. Analyses of the crude wax produced from the "as is" mud showed 44.2% wax, 40% oil and 15.8% resins, which are comparable to those for commercially produced sugarcane wax.

Present data indicates that a mild planetary mixing action is necessary to obtain high extraction efficiencies from U.S. sugarcane muds. The extraction efficiencies of approximately 85% obtained on a laboratory scale are higher than that (70%) for commercial extraction in Cuba. In Cuba, this planetary type action is apparently not necessary since commercial extraction is carried out in a 9-ft-diameter vertical extraction chamber in which the wet muds and heptane are contacted by means of a slowly rotating paddle. Another factor which may determine the type mixing needed may be the variety of cane grown. If this is so, muds in Cuba may possibly be suitable for processing by filtration-extraction after slurrying by paddle mixers only, thus eliminating the need for a planetary mixing operation. Bench-scale work may show that simple mixing devices may replace the planetary-type mixing, since only a mild agitation is required.

Fig. 3 shows how the filtration-extraction process could be applied to sugarcane muds to produce crude waxes.

REFERENCES

1. Avequin, J. B., *Ann. chim. phys.*, [2], **75**, 218-22 (1840); *Ann.*, **37**, 170-3 (1841); *J. prakt. Chem.*, **22**, 238-42 (1841).
2. Balch, R. T., "Wax and Fatty By-products from Sugarcane", Sugar Research Foundation, Technol. Rept. Ser. No. 3, 62 pp. (1947).
3. Daugherty, P. M., Sineath, H. H., and Wastler, T. A., *Georgia Eng. Expt. Sta. Bull.*, **17**, 36 pp. (1953).
4. D'Aquin, E. L., Spadaro, J. J., Graci, A. V., Jr., Eaves, P. H., Molaison, L. J., Knoepfler, N. B., Crovetto, A. J., Gardner, H. K., and Vix, H. L. E., *J. Am. Oil Chemists' Soc.*, **31**, 606-613 (1954).
5. D'Aquin, E. L., Vix, H. L. E., Spadaro, J. J., Graci, A. V., Jr., Eaves, P. H., Reuther, C. G., Jr., Molaison, L. J., McCourtney, E. J., Crovetto, A. J., Gastrock, E. A., and Knoepfler, N. B., *Ind Eng. Chem.*, **45**, 247-54 (1953).
6. Decossas, K. M., Many, H. G., McMillan, O. J., Jr., Gastrock, E. A., and Pollard, E. F., *Ind. Eng. Chem.*, **49**, 930-5 (1957).
7. Dumas, J., *Ann. chim. phys.*, [2], **75**, 222-3 (1840); *Ann.*, **37**, 173-5 (1841); *J. urakt. Chem.*, **22**, 242-3 (1841).
8. Gastrock, E. A., *Soybean Digest*, **16** (12), 18-20 (1956).
9. Gastrock, E. A., Spadaro, J. J., and Graci, A. V., Jr., *Soybean Digest*, **13** (8), 16-17 (1953).
10. Gastrock, E. A., Persell, R. M., Spadaro, J. J., and Vix, H. L. E., *Oil Mill Gaz.*, **54** (3), 11-18 (1949).
11. Graci, A. V., Jr., Spadaro, J. J., Paredes, M. L., D'Aquin, E. L., and Vix, H. L. E., *J. Am. Oil Chemists' Soc.*, **32**, 129-31 (1955).
12. Graci, A. V., Jr., Reuther, C. G., Jr., Eaves, P. H., Molaison, L. J., and Spadaro, J. J., *Am. Oil Chemists' Soc.*, **30**, 139-43 (1953).
13. Haines, H. W., Jr., Perry, G. C., Gastrock, E. A., *Ind. Eng. Chem.*, **49**, 920-9 (1957).
14. Honig, P., "Principles of Sugar Technology", Elsevier Publishing Co., Amsterdam, 1953, 767 pp.
15. Knoepfler, N. B., and Vix, H. L. E., *J. Agr. Food Chem.*, **6**, 118-21 (1958).
16. Kurth, E. F. (to State of Oregon, through Oregon State Board of Forestry), U.S. Patent 2,662,893 (December 15, 1953).
17. Lewy, B., *Ann. chim. phys.*, [3], **13**, 438-60 (1845); *J. prakt. Chem.*, **36**, 65-83 (1845).
18. McLand, E. S., "Sugarcane Waxes". Paper presented at the Chemical Specialty Manufacturers Assoc. Meeting, June 12, 1950.
19. Pominski, J., Eaves, P. H., Vix, H. L. E., and Gastrock, E. A., *J. Am. Oil Chemists' Soc.*, **31**, 451-5 (1954).
20. Pominski, J., Decossas, K. M., Eaves, P. H., Vix, H. L. E., and Pollard, E. F., *Ind. Eng. Chem.*, **47**, 2109-11 (1955).
21. Pominski, J., Spadaro, J. J., and Vix, H. L. E., *Sugar J.*, **20** (2), 17, 38 (1957).
22. Rhodes, F. H., and Swenson, O. J., U.S. Patent 2,428,813 (Oct. 14, 1947).
23. Scott, Walter, "The Industrial Utilisation of Sugar Cane By-products", pp. 94-101, Kent House, Port of Spain, Trinidad, 1950.
24. Spadaro, J. J., Graci, A. V., Jr., Gardner, H. K., Parker, J. S., Laborde, E. J., and Gastrock, E. A., *Oil Mill Gaz.*, **56** (1), 77-81 (1951).
25. Swenson, O. J. (to Colonial Sugars Co. and S. C. Johnson & Son Inc.), U.S. Patent 2,456,655 (Dec. 21, 1948).
26. Swenson, O. J. (to Colonial Sugars Co. and S. C. Johnson & Son Inc.), U.S. Patent 2,456,656 (Dec. 21, 1948).
27. Swenson, O. J. (to Colonial Sugars Co. and S. C. Johnson & Son Inc.), U.S. Patent 2,464,189 (Mar. 8, 1949).

Erratum

Diffusion in Dilute Solutions—A New Correlation, p. 795 (November)

In the table of *Symbols Used*, the symbol for viscosity, poise; should be μ not φ, and on page 796

$$\varphi = \frac{\text{Surface Tension of Solvent}}{\text{Surface Tension of Water}}$$

, not the reciprocal. However, both terms were correctly used in the text.

THE GROWING USE OF ALUMINIUM*

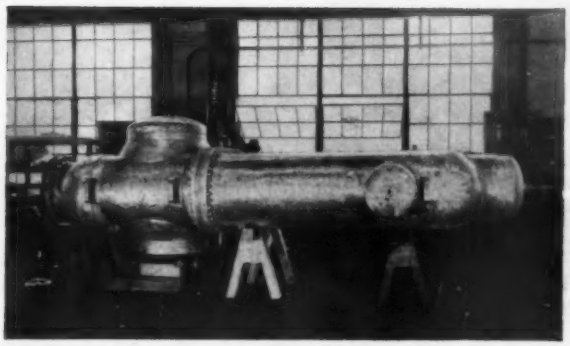

Fig. 1. *An aluminium heat-exchanger unit.*

Fig. 2. *An aluminium extractor column for hydrogen peroxide production.* (*Photo courtesy A.P.V. Co. Ltd.*)

ONE of the difficulties always facing the chemical engineer when planning a new plant is to choose suitable materials for its construction. The very corrosive nature of the chemicals involved in the process, together with the need for strength formability and weldability, often pose some difficult problems. Stainless steel is widely used, and new plastic linings are becoming increasingly important, but aluminium can offer the chemical engineer a unique combination of properties often not to be found in any rival material. With its combination of lightness and strength, ease of fabrication and good resistance to corrosion, it is an excellent material for handling a wide variety of chemicals. The rubber, paper, textiles, explosives and paint industries are major users and the food industry too is using it increasingly.

For most purposes in the chemical industries the metal of 99.5% purity is used. In this form it is comparatively low in strength, but suitable for containing vessels. Its properties may be developed to meet particular needs by adding small quantities of other elements such as magnesium, silicon or manganese. *Wrought* alloys are used mainly as sheet for vessels and as tubing for pipework; *cast alloys* are used in valves, fittings and pump casings. Aluminium is available in the form of sheet, plate, extrusions, tube, wire and forgings.

Aluminium and its copper-free alloys are finding important uses in hydrogen peroxide operations, particularly for the fabrication of transport containers and storage vessels.

In the nitric acid industry aluminium is remarkably resistant to corrosion from concentrated and fuming nitric acid.

Refined petroleum does not attack aluminium and this property, combined with lightness, high reflectivity and low tendency to spark, increases its usefulness in this sphere. Its high resistance to corrosion by sulphur compounds in the oil and by leaded fuels makes aluminium an important fabrication material for distillation columns, bubble caps, condensers, heat exchangers and transport tankers.

At low temperatures aluminium does not become brittle and has advantages over steel in this respect. It is the most suitable material for bulk storage of liquefied gases, and is cheaper than copper. For low-temperature hydrogen distillation units and similar apparatus aluminium is ideal.

The largest aluminium rolling mill in Europe, at the Rogerstone, Monmouthshire, works of Alcan Industries Ltd. (formerly the Northern Aluminium Co.), was recently extended by the inclusion of a new 144-in. hot mill and other units.

FIELD-MARSHAL the EARL ALEXANDER OF TUNIS, K.G., chairman of Alcan Industries Ltd., explained at a reception held recently how this expansion scheme was designed to meet the changing pattern of demand, in particular the growth of interest in the aluminium-magnesium alloys. The availability of wide plate would, he said, be of significance to the shipbuilding, railway, chemical and general engineering industries, offering savings in construction costs.

* With acknowledgments to Alcan Industries Ltd. for their help in supplying information and photographs.

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The Avenue carbonisation and chemical plant. (With acknowledgments to Woodall-Duckham Construction Co. Ltd.)

THE PURIFICATION OF COKE OVEN GASES WITH PLATINUM METAL CATALYSTS

by H. C. ANDERSEN and D. R. STEELE*

THE purification of coke oven gas from various impurities has concerned chemists for many years. The useful constituents of coke oven gas are hydrogen, carbon monoxide, methane, nitrogen and ethylene. The components generally considered undesirable are sulphur compounds, oxides of nitrogen, acetylene and diolefins. The small concentration of oxygen in most coke oven gases is usually not undesirable.

When coke oven gas is to be used as a fuel, it has been found that gas-burning appliances tend to plug with gum formed by interaction of nitrogen oxides and diolefins.[1] One solution to this problem is to permit the gum to form in a low-temperature volume provided for this purpose; the gum deposits are then removed periodically.[2] However, this solution is not entirely satisfactory, as the deposits may be explosive.[3] The nitrogen oxides problem has been discussed, mostly from the standpoint of gas analysis, by several workers in the field.[4, 5, 6, 7]

When coke oven gas is employed for various syntheses, the problem is even more serious. For example, coke oven gas, partially purified by removal of CO_2 and H_2S, may be cooled, partially liquefied, and fractionated into a hydrogen fraction and a hydrocarbon-rich fraction. The former can be used for ammonia synthesis, and the latter, being high in ethylene, for the manufacture of ethylene derivatives. In the liquefaction step, acetylene may deposit as a solid until dangerous amounts accumulate. Accordingly, it is necessary to reduce the acetylene to a concentration below its limit of solubility in ethylene.

In response to this technical problem, methods have been developed for removing acetylene from coke oven and similar gases by means of hydrogenation over platinum metals catalysts.[8] It has now been found that catalysts of this type will remove not only acetylene, but also nitric oxide, diolefins and carbonyl sulphide. Temperatures and space velocities are generally more favourable than those necessary for nitrogen oxides and acetylene removal with sulphide catalysts.[9]

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In catalytic treatment, the impurities are converted as follows:

Impurity	*Product*
NO, NO_2	NH_3 (N_2)
C_2H_2	C_2H_4 (C_2H_6)
Diolefins	Olefins
COS	H_2S

In the first three cases, the impurity can be removed to the level of parts per million or a fraction of a part per million. In the case of COS, removal is limited by equilibrium for the reaction:

$$COS + H_2 = CO + H_2S \quad \ldots . (1)$$

Calculation shows that, in a gas containing 50% H_2 and 10% CO, the COS can theoretically be reduced to 2.5 to 4.7% of its inlet concentration in the temperature range 260°—199°C.

Catalytic removal of the impurities occurs over a considerable range of pressure, temperature and gas composition. The effect of sulphur compounds is to raise the temperature otherwise required for purification. The carbon monoxide may vary over wide limits and has the effect of improving selectivity in conversion of acetylene to ethylene. Thus, at low CO values, a slight net loss in ethylene concentration takes place; at sufficiently high CO values the ethylene concentration is increased by an amount equal to the inlet acetylene.

The catalysts of this study consist of platinum group metals supported on an ¼-in. cylindrical pellet. There is a degree of specificity of catalyst with respect to the individual purification reaction, and the preferred catalyst metals are as follows:

Impurity to be removed	*Preferred catalyst*
C_2H_2	Pd
NO, NO_2	Ru
C_2H_2, NO, NO_2	Pd + Ru
	Pt
Diolefins	Ru
COS	Pd + Ru

TABLE 1—Catalytic Purification of Coke Oven Gas (180–220°C)

Catalyst — 4 ml. Supported Pd + 4 ml. Supported Ru

Gas Flow — 32 Litres per hr (NTP)

Inlet Gas—H_2—59.8%, CO—10%, CH_4—28%, C_2H_4—2% plus others as shown

Pressure, atm.	O_2 ppm in	COS ppm in	COS ppm out	NO ppm in	NO ppm out	C_2H_2 ppm in	C_2H_2 ppm out	Other compounds identified in outlet gas
1	0	0	0	30–70	< 0.3	2000	< 2	1.8% C_2H_4
1	0	20	—	30–70	< 0.3	2000	—	
1	1700	20	—	30–70	< 0.3	2000	8	0.3% CO_2
1	2000	100	25	30–70	< 0.3	2000	50	H_2S
14	2000	200	< 10	30–70	0.01	2000	< 2	
14.7	2000	400	25	30–70	< 0.02	2000	< 2	0.03% H_2S

— Not determined.
Number following < indicates limit of detection during the experiment.

TABLE 2—Catalytic Removal of Diolefins

Catalyst —Supported Ru
Inlet Gas —60% H_2, 10% CO, 30% N_2, plus other constituents as shown
Pressure—Atmospheric
Space velocity—8000 LPH/L catalyst (NTP)

Inlet gas additions, ppm			Catalyst temperature, °C	Outlet gas, ppm			
Diolefin	Other			Diolefin	C_2H_2	C_2H_4	other
	C_2H_2	C_2H_4					
Butadiene—1000	500	500	100	960	500	500	
			210	1000	< 2	400	
			225	< 50	< 2	500	Butene-1
Cyclopentadine 32,500	0	0	120	1300			
			150	1040			
			175	260*			

* Limit of detection.

It is apparent that a catalyst or catalysts can be provided to remove all the impurities, if desired. Nickel may also be used for some of these purifications, but it has an unfortunate pyrophoric tendency which makes it hazardous to handle after running under reducing conditions. Also, it may form gaseous carbonyls when operated at low temperatures.

Some examples of purification with the platinum metals catalysts follow:

Acetylene

A laboratory life test of more than 3000 hr was made, in which acetylene was removed from a gas containing 0.15% C_2H_2 2.4% C_2H_4, 8.0% CO, 37% N_2, 52% H_2 and 0.015% COS.[10] Subsequent operation of a full-scale plant in continental Europe has proved satisfactory for about two years.

Acetylene, Nitric Oxide, Carbonyl Sulphide

These three impurities were removed from a laboratory gas mixture prepared to simulate coke oven gas. The data are given in Table 1.

At atmospheric pressure, nitric oxide was removed readily in the presence of COS, but acetylene removal deteriorated slightly. The COS itself was partially converted to H_2S. In the presence of sulphur, oxygen had the effect of improving the completeness of NO removal at a given temperature; the oxygen was converted largely to CO_2.

At elevated pressure, 14-14.7 atm, acetylene and carbonyl sulphide removal was more complete than at atmospheric pressure. Acetylene and nitric oxide were both removed to concentrations near the limit of detection. Carbonyl sulphide was reduced to 5-6% of its inlet value, which is near the equilibrium limit cited previously.

Ethylene preservation was good in all cases where analysis was made. With 200 ppm COS in the feed, there was a slight increase in the ethylene concentration over the catalysts.

Even after exposure of the catalysts to pure hydrogen sulphide, they were effective in purification. The data of Table 1 were taken over a period of almost 3000 hr, and there was no indication of activity loss for this time. For example, acetylene was removed to less than 2 ppm from a sulphur-free stream at 146°C after 2816 hr.

Acetylene and nitric acid were also removed from a gas much richer in carbon monoxide:

%		%	
4	H_2	0.8	N_2
80.2	CO	0.1	COS
10.0	CO_2	0.1	H_2S
4.0	CH_4	0.01	NO
0.5	C_2H_4	0.2	O_2
0.1	C_2H_2		

The operating pressure was 21 atm, and removal of impurities for temperatures of 200-300°C was good. Regeneration of the platinum catalyst to burn off carbon deposits appeared to be required at monthly intervals.

Diolefins

Limited experiments showed that both butadiene and cyclopentadiene were removed from a coke oven gas at atmospheric pressure (Table 2). A temperature can be selected at which both acetylene and diolefin are completely removed, but the ethylene preserved. Catalytic treatment thus appears to remove both constituents which are required to produce vapour-phase gums; namely, diolefins and nitrogen oxides.

REFERENCES

[1] C. W. Jordan, A. L. Ward and W. H. Fulwiler, *Ind. Eng. Chem.*, **26**, 947-55 (1934).
[2] English Patent No. 754,698 (August 8, 1956), to Thyssensche Gas-und Wasserwerke G.m.b.H.
[3] *Chem. Eng. Progress*, **55**, 49-54 (1959).
[4] A. Guyer and R. Weber, *Brennstoff-Chemie*, **14**, 405-8 (1933).
[5] H. Seebaum and E. Hartmann, *Brennstoff-Chemie*, **16**, 41-7 (1935).
[6] G. Berkhoff and M. F. van den Bout, *Het Gas*, **4**, 53-9 (1939).
[7] J. Pierrain, *Chimie et Industrie*, **70**, 189-96 (1953).
[8] *Engelhard Industries' Communications*, **1**, No. 1, June, 1960.
[9] M. P. Korsh and F. P. Ivanovskii, *Zhur. Prik. Khim.*, **10**, 1561-8 (1956). 1561-8 (1956).
[10] H. C. Andersen, A. J. Haley and W. Egbert, *Ind. Eng. Chem.*, **52**, 901-4 (1960).

Fig. 1. A general view of the Fair ground taken at a period when the general public was excluded. In the distance is Pavilion Z, where most of the chemical plant was exhibited.

THE BRNO TRADE FAIR

THE second International Engineering Exhibition, held last autumn in picturesque surroundings on the outskirts of the Moravian capital, proved to be an even more interesting and pleasant event that its predecessor of last year. Commercially, too, it was more successful and the value of business transacted exceeded last year's turnover by 13%.

In a number of other respects the Fair this year differed from last year's. First, a definite attempt was made to group together machinery according to its type. Special periods were provided in which the general public was excluded so that business contacts could be made without unnecessary hindrance, and films, conferences, specialist days and lectures on theoretical engineering problems and on outstanding achievements in many fields were other valuable features of the Fair. Unfortunately, only a few of these facilities were devoted to fields of direct interest to chemical engineers, but in future exhibitions this situation is likely to be improved.

Another respect in which the exhibition differed was in the larger British representation, although, in the field of chemical plant, of the Western firms the greatest impact was made by those from West Germany, and one field in particular which was much more in evidence than last year was that of automatic control and scientific instruments. In this respect British firms were fairly prominent.

Typical of the attention to detail in evidence at the Fair was the provision of an organisation whereby foreign exhibitors were given the opportunity of buying or selling licences and concessions for new designs of engineering and scientific equipment. This service was provided by the Czechoslovak body, Polytechna, which is known to be especially interested in chemical engineering developments.

Ancillary Equipment

Valves for process applications were well represented by Langley Alloys, whose display of stainless-steel components was particularly appropriate in view of the rapid development of the chemical industry planned in the socialist countries. Although the equipment shown was not claimed to be entirely novel, nevertheless, it was sufficient to show Langley's ability to meet virtually any valve requirement of the chemical industry. All the valves shown were made from special alloys, including Langalloy 3V (18/8/3 Mo) and Langalloy IV (18/8/1 Nb) and also Langalloy 20V, an alloy specifically developed for handling various concentrations of sulphuric acid up to approximately 80°C. Of recent introduction was a PTFE-sleeved plug cock, available in sizes up to 4 in. n.b. in 150-lb and 300-lb ratings. It is worth noting that valves of this kind have given more than five years' service in corrosive environments without attention. The types shown were 150-lb gate, two-piece body "Y" globe valves and lift and swing check valves.

Other exhibitors to show valves for chemical service were Strojexport and the Austrian concern, Audco Rockwell. The wide range of the former covered most of the types required in industry and included some lead models. Three varieties were shown, a "Y" type and a normal globe valve with backseating, packed stuffing box, a spindle locking bolt and a gland cock in either two- or three-way patterns; they are suitable for working pressures of 6 kg/cm² at 80°C or 2 kg/cm² at 120°C; the bore of the "Y" valve is 25 mm and the other two models are supplied in 40-, 60- and 80-mm sizes.

The range of lubricated plug valves shown by Rockwell included many models with which British users are familiar, but which were less well known at Brno. They were the sole representatives of their type at the Fair.

Pumps

Pumps of many kinds were to be seen, including a number suitable for chemical duties such as a glass centrifugal pump shown by Technoexport. This pump, which does not appear to differ much in mechanical design from metallic pumps, is available in three sizes and uses an open impeller (Fig. 3) and will tolerate liquids at 50°C. The suction cover is easily removable for cleaning the pump and the impellers are readily replaced. Characteristics for the three sizes are shown in Fig. 4.

Technoexport also had on view an all-lead pump, available in six sizes, of the enclosed impeller type. The suction side of the pump is easily dismounted to give access to the impeller, and shaft sealing is by readily replaceable stuffing-box packings.

The Royal Dutch Engine Works had an excellent display of chemical pumps, available in a number of materials of construction. They included a stainless-steel type with an easily dismountable open impeller and capable of outputs up to 30 m³/hr for heads approaching 75 m. A very robust stepped impeller shaft is employed, mechanically sealed. Another pump can be supplied in cast iron, acid-resisting bronze, tin bronze and 30% Cr alloy. This is a closed-impeller type specially designed to prevent the formation of foam. Capacities are up to 30 m³/hr for heads up to 50 m.

For thick liquids the same company supplies a pump with larger passages in impeller and casing, in this case the capacities being up to 50 m³/hr for heads approaching 70 m. Finally, special process pumps were shown manufactured from polyesters and from such special materials as 14% Si, 3% Mo cast iron and 30% Cr, 4% cast iron. Useful design points are readily packed gland and easily detachable casing from the main pump body.

Metering Pumps

A metering pump specially designed for processing duties which caught the eye, mainly on account of its clearly easy adjustment of throughput, was displayed by Dipl-Ing Rudolf Hauke. Suitable for such applications as pH control, these robust pumps are available with their reagent-contact parts in special alloys such as plastics, PTFE, PVC, polyethylene.

The piston stroke is adjustable while the pump is operating, a handwheel with indicator and graduated scale being provided for this purpose. Maximum capacities vary from 7-3000 litres/hr and delivery pressures from 3-300 atm.

The most novel pump of this kind, however, was shown by Strojexport. Instead of a piston or diaphragm, this pump employs a corrugated tube or bellows as the pumping element which is compressed by the action of fluid from a separate plunger pump and returned to its original position by means of a spring. The delivery is controlled by a simple manual micrometer adjustment to the plunger pump. The corrugated tubes can be supplied in stainless steels or in plastic materials. Maximum capacities range from 1.5-800 litres per hour with pressure delivery in the range 64-320 atm. Some of the pumps are fitted with as many as four tubes so that they can deliver, if required, four different liquids. The pump is limited in its application to liquids free from solids, and it must be installed with a flooded suction of at least 0.5 m.

It is particularly suitable for volatile or viscous liquids.

Closer to the chemical plant field was the plate-type evaporator shown by A.P.V. The particular equipment shown comprised one effect of a unit for the concentration of apple juice (to 70% total solids). Although this exhibit attracted its fair share of attention, one felt, in view of the appearance of competitors' equipment, that it was a pity that the other types of chemical plant for which A.P.V. has a high reputation, such as distillation plant, were not shown.

Examples of Fabrication Equipment

A number of examples of chemical plant fabrication were to be seen. Technoexport, for example, showed a number of low-temperature heat exchangers and a regenerator valve. One exchanger was part of the equipment for a synthesis gas plant where raw hydrogen is scrubbed with

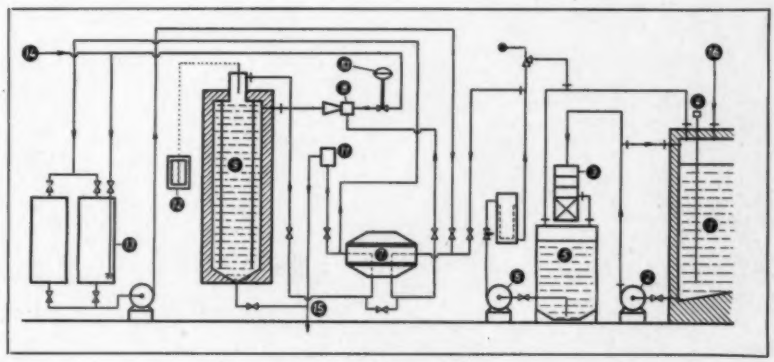

Fig. 2. Reflecting current efforts to conserve water and to prevent pollution—a Carl Canzler plant for the treatment of infected waters from hospitals, etc.

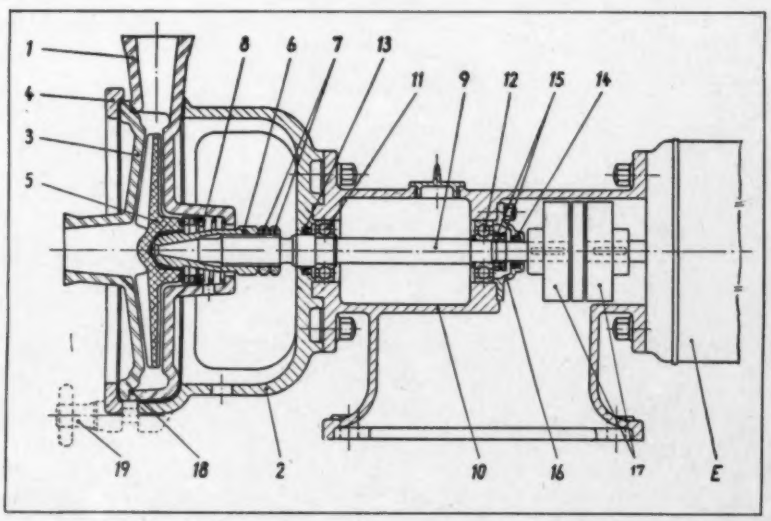

Fig. 3. A glass horizontal single stage open impeller pump with stainless steel impeller shaft manufactured by the Czech firm, Sigma. At present produced in three sizes (see Fig. 4 for characteristics), further larger versions are being developed for process applications.

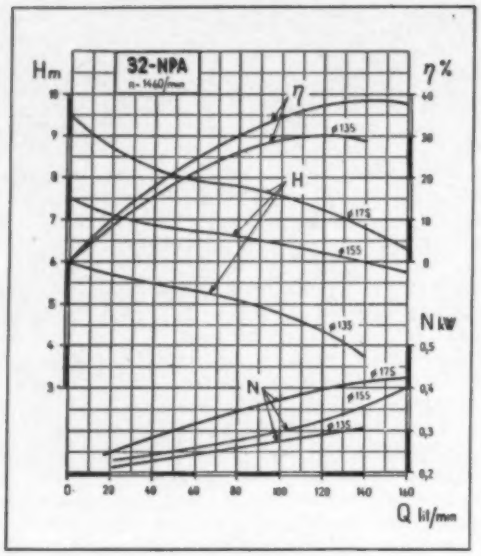

Fig. 4. Characteristics of glass centrifugal pump shown in Fig. 3.

Fig. 5. A scene on the Niro stand. Two stainless-steel components of a spray drying plant.

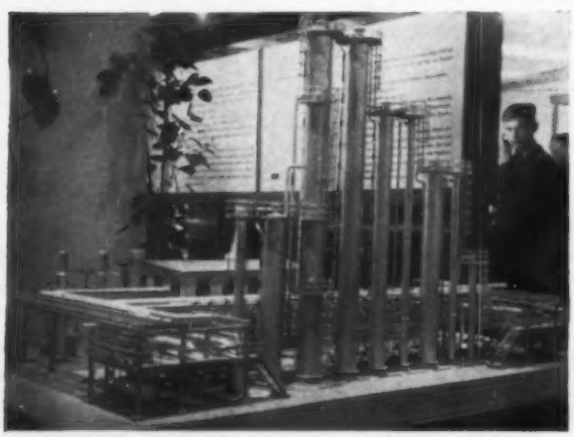

Fig. 6. One of the most impressive stands in the Exhibition. An ethylene plant model on the Lurgi stand.

liquid nitrogen. The surface is made by 11 km of 10 × 1 mm copper tubing. In fact, 721 tubes are used, each 15.5 m in length. A feature of the design is the method of connecting the header at the lower end by means of a specially flanged joint of Czech design. The area provided is 285 m² for a load of 600,000 kcal/hr.

Another exchanger of unconventional design was equipped with a forged shell, forged branches connected by threaded flanges fitted with lens ring packing. The branches on the shell were similarly forged and connected by conical threads secured by a packed welded joint. The inside surface of the apparatus was aluminised, as were the tubes. The working conditions of the exchanger were pressure 50 atm and temperature 450°C in both shell and tubes, the shell- and tube-side fluids being hydrocarbons.

A novel method of constructing large storage tanks was shown on behalf of the local firm, the Kralovopolska Works, Brno. In this new method, by means of a compact rolling machine the plates already rolled to the required radius are wound helically upward; the rolls are driven electrically, the edge of each plate tack is welded to the plate beneath, while the final welding is carried out automatically. The method eliminates the need for scaffolding, and offers a saving in erection labour of the order of 70-80%. This method of fabrication was used for storage tank construction at the refinery at Homs in Syria, where it contributed to the rapid erection of the plant, which was completed and on stream in less than 23 months from the time of the signing of the contract.

Complete Processes

What must have been the largest model of a chemical plant ever to appear at a European exhibition was shown in the Russian pavilion, where it stood in company with a display of books covering a wide range of scientific and engineering topics, instruments, computers, machine tools and automobiles. It represented a butadiene plant, itself part of a large synthetic rubber plant at Sumgait in the Azerbajanian S.S.R. and one of several now either planned or in course of erection in the Soviet Union. The unit, with an annual output of approximately 6-8 × 10^4-tonnes of butadiene per year, uses a two-stage process for the catalytic degradation of butane, the butylene-yielding first stage employing a fluid-bed catalyst with continuous regeneration, and with the butadiene emanating from a fixed-bed reaction system. A host of columns, some with bubble-cap trays, others with grid-trays in the full-scale version, are employed for a number of separations. Thus extractive distillation separates butane from butylene, butylene from butadiene by absorption and stripping, with a final purification treatment of the butadiene by means of ammoniacal copper salt solution. No claims of overall novelty were made for this process, although it is evident that the basic engineering is essentially of Russian origin. Unfortunately, a mishap with the editorial camera prevented illustrations of this model from appearing in this issue.

Another now well-established process displayed in model form by Lurgi was their fluidised-bed cracking process for the manufacture of olefins from virtually any mineral oil product from Lpg to fuel oil. The heart of this process is the reactor for converting the heated vaporised feed at 300-400°C, to olefin. Reaction heat is provided by the fluid bed of hot sand particles. Reaction temperature, according to feed and product desired, is maintained within the limits 720-850°C, and residence times are 0.4-0.6 sec. The hot sand is removed continuously and lifted pneumatically by hot gases to a feed vessel before re-entering the reactor in a heated condition. The heat is supplied to the sand through the combustion of oil recovered from the electrofilter (used for removing mist from the cracked gases) and of the coke deposited upon the sand itself.

The quantity of heat required at the reactor is controlled by the burning process occurring in the lift pipe. After passing through a number of stages to remove water, medium oil, benzene and for cooling, the gases proceed to a gas separation plant for recovery of the individual olefins.

Yields of olefins range from 60-40% according to feed stock, the higher figure being obtained with ethane and the lower with Irak crude. The main economic features of the process are, per metric ton of C_2 to C_4 olefins: raw material 320-450 kg fuel oil, power consumption 100-130 kWh, cooling water 70-100 m³, sand (0.4-1.5 mm particles) 50-100 kg. Process and other steam requirements are provided by waste heat boiler.

Last year the largest single exhibit was a Czech made rotary cement kiln, an important feature being the variable-speed hydraulic drive provided by a group of small pumps operating in parallel. This year, in a model of a wet process cement plant, a similar kiln of output 500 tons /day was one of the major pieces of equipment. A noteworthy point in the design of the kiln, apart from its hydraulic drive, is the extended drying zone with integral slurry heater together with chain lifters and a system of blades of heat-resistant steel, features which make for greater fuel economy and, more important, reduce dusting to a minimum. In the model of the plant, which is understood to be typical of several existing installations, special dust-removal devices were not present, since in the majority of actual cases their inclusion has not been required.

Simon Handling (Engineers) Ltd. made use of a flow diagram illustration of the various handling and processing operations required in a modern rubber tyre factory. An important part of the installation is the automatic weighing and proportioning equipment for controlling the materials to be fed to the mixer such as oils, powders, e.g., accelerators/fillers, and rubber. This gave the visitor a good impression of the type of materials handling project which the company can undertake, including its ability to provide pleasant working conditions by means of adequate dust control equipment.

Vacuum-drying Equipment

Equipment of this kind was not a great deal in evidence, but the East German company, Dreyer and Holland-Merten G.m.b.H., showed a freeze drying plant and displayed pictorially a number of their latest processing units. One such was a thin-film multistage degassing plant for the treatment of viscous and liquid synthetic resins, and for imparting uniform foam-like structures to very viscous liquids. This equipment is supplied in packaged units with plate and frame filter for clarifying the liquid feed before degasifying. Heating is by either steam, hot water or electrical resistance. Capacities range from 0.5-5 m³/hr of gas removed. Energy consumptions are 2-12 kW, and electrically-heated plants require 12-75 kW at the elements.

A vacuum drier for solids also depicted on this stand consisted of a stationary drum in which rotates a hollow shaft carrying a nest of tubes for the heating surface, as well as a system of agitator blades. Two varieties of blading are available, one consisting of wiper-scraper elements, and the other is a more complex arrangement to give a high degree of mixing to the solids being processed.

The available range offers a heating surface of 22-135 m² with a working volume of 1.1-6.5 m³.

Heat Transfer Equipment

A stand which was often crowded was Carl Canzler's, much of the attraction being due to the presence of a universal pilot plant, designed on the unit construction principle so that users can purchase the basic elements initially and add to them later when desired. The main

Fig. 7. Valves for the chemical industry shown by one of the British exhibitors.

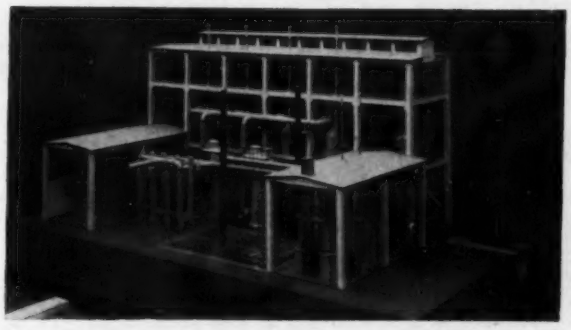

Fig. 8. A 10,000 Nm³ gas generating unit for brown coal shown by Gabor Aron of Budapest.

Fig. 9. A scene at the A.P.V. stand. A plate evaporator for fruit juices.

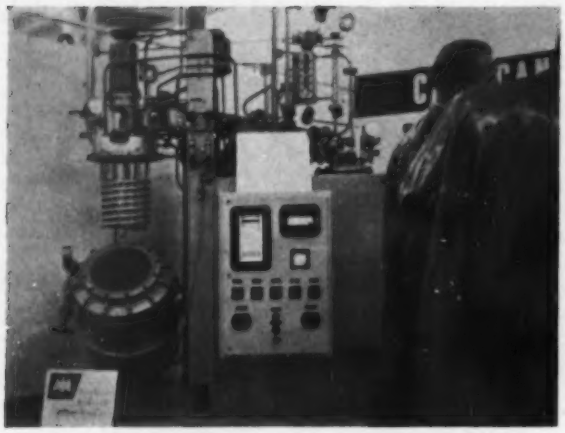

Fig. 10. A universal pilot plant shown by Carl Canzler. This versatile unit aroused much interest.

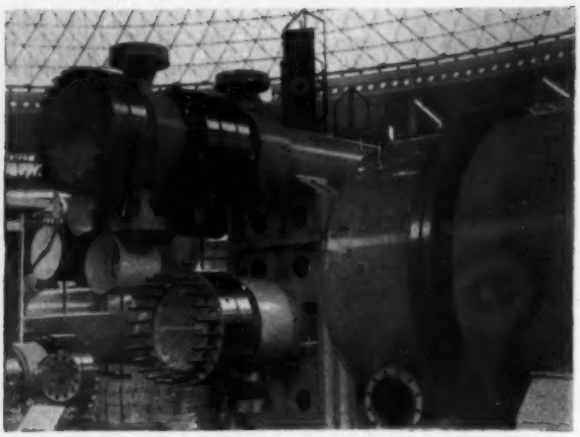

Fig. 11. Examples of chemical plant construction from Kralovopolska Engineering Works.

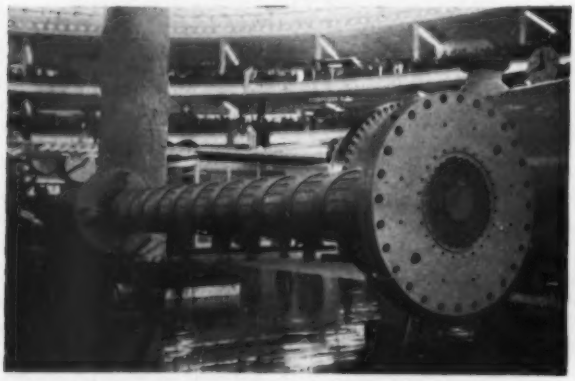

Fig. 12. An example of a low-temperature heat exchanger made by the same company.

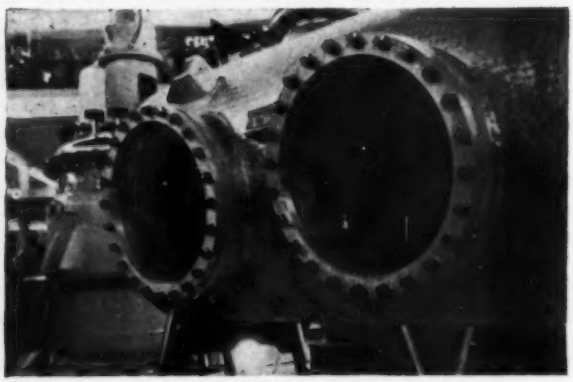

Fig. 13. The regenerator valve of a gaseous oxygen plant. This component deals with the nitrogen stream.

component (Fig. 10) is the agitated vessel which can be heated up to 350°C. It is constructed of Mo-bearing stainless steel, the various agitating elements are interchangeable and a 10:1 rotational speed variation can be provided; heating is either by electric resistance elements or by an electro-diphenyl heating system.

Other Canzler equipment shown pictorially included a plant for treating infected waters such as would be discharged from hospitals (Fig. 2) and, a special feature not depicted elsewhere in the Exhibition, induction-heated chemical reactors: this system has a number of advantages such as uniform distribution of temperature around vessel walls, and high energy fluxes much in excess of 2 W/cm² of heated surface. In addition, temperatures of up to 500°C and accurate control are readily achieved.

Constructions include a rotary nickel-clad autoclave approximately 4 m in length and 0.95 m diameter, with a working capacity 3.5 m³.

Energy supply is 420 kW (p.f. 0.8), working pressure and temperature are 50 atm and 270°C respectively.

Process Control Instruments

Perhaps the most impressive of the British exhibits was in the field of instrumentation, where British prestige, so to speak, was upheld by such companies as the Cambridge Instrument Co., Hilger & Watts, Solartron, Unicam and Griffin & George.

A novel instrument was shown by Cambridge for measuring extrusion speed. With it the measurement of extruder ram speed is converted into a proportional electric current which can operate a number of separate indicators and recorders. It is applicable to machines producing a linear or equivalent rotational movement.

They showed further an electro-pneumatic programme controller with proportional action; used in conjunction with two measuring systems, it can control two separate variables and switch in and out a number of process functions: and a dissolved oxygen analyser capable of detecting 1 gramme of oxygen in 2,000,000 kg of water. This instrument has six ranges, the most sensitive being 0-0.01 ppm full scale. Finally, mention should be made of the recently-introduced pocket pH metre with a scale 0-14 pH and an accuracy of ±0.1 pH.

Solartron concentrated on data handling equipment, including a digital data recorder capable of recording analogue signals with an accuracy of ±0.1% and suitable for plant monitoring, whereas Hilger & Watts displayed a number of new instruments whose interest lay in other fields of engineering. Of the other British exhibitors, Unicam presented spectrophotometers of various types.

Electrical, pneumatic and electro-pneumatic controllers and data handling equipment were in evidence as well as a number of instrument panels (graphic and otherwise) on stands of the Czech organisation, Kovo.

Another firm to show electrical automatic process control equipment was Siemens & Halske, whose display was impres-

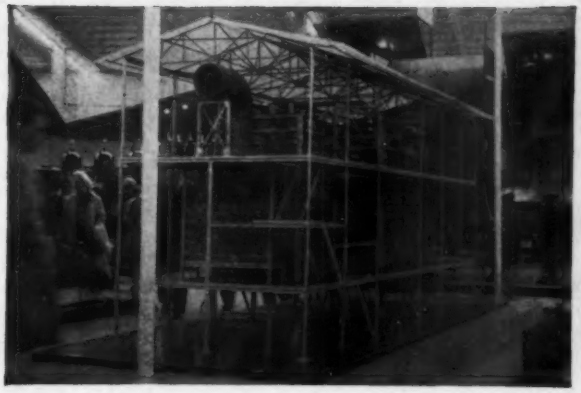

Fig. 14. An electro-precipitator mainly in lead displayed by Technoexport for chemical plant service.

Fig. 15. A continuous Czech centrifuge. This machine has an output of 4000 kg/hr of crystalline solids.

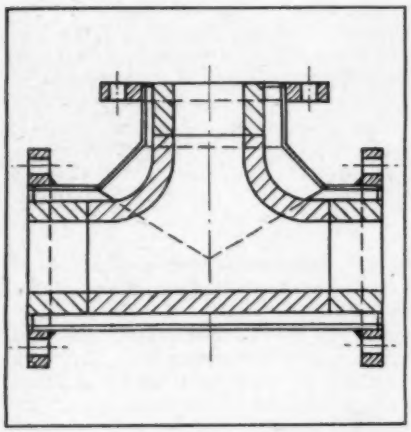

Fig. 16. Crystallised basalt products were shown by Czech Ceramics—a lined 'Tee'.

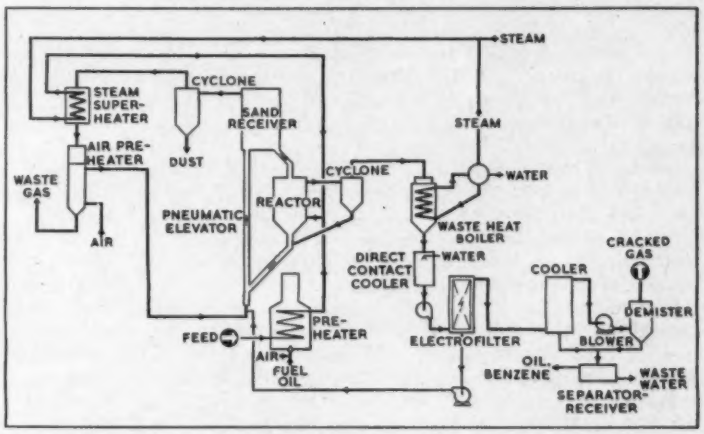

Fig. 17. Flow diagram of a Lurgi fluid bed process for the manufacture of olefins from crude oil, etc.

sive, particularly the examples of the Siemens electro-pneumatic controllers.

Similarly impressive were the exhibits of GST (Schellhase & Co.), who also showed various elements of electro-pneumatic systems for measuring most process variables. Among the new pieces of equipment appearing on this stand was a compact controller available with either three-term or proportional integral action.

The sole representative of the inductive instrument for measuring flow concentration or density was Alto of the Netherlands N.V., who indicated that they can now supply their metering tubes in diameters up to 1 m for flow rates up to 4000 m^3/hr.

Compressors

CKD compressors were the outstanding exhibits in the compressor field, their machines being shown on a number of the Technoexport stands. The models displayed were radial and axial flow turbo machines and piston compressors. Among radial types, three models in particular caught the eye; a blast furnace blower with a delivery of 270,000 sm^3/hr at 3.8 atm driven by a 17-mW condensing turbine and provided with interstage cooling; a high-pressure machine with an intake of 150,000 sm^3/hr delivered at 9 atm—a model available in a range of sizes; and the refrigeration plant "Dana" compressor shown for the first time last year with a "cold" output of 3 million kcal/hr.

Axial machines for the compression of gases to low and medium pressures have efficiencies superior to those of radial machines, and the CKD designs are 8-10% more efficient than their radial counterparts. This, for a volume at the suction of 270,000 Nm^3/hr compressed to 3.8 atm, represents a saving of 2000 kW. One such compressor on view was part of a 6-MW gas turbine unit, delivery was 220,000 Nm^3/hr at 4 atm, adiabatic efficiency greater than 89%, and similar machines are now in service at blast furnaces with deliveries of 400,000 Nm^3/hr.

Other examples of compression machinery were shown by the companion-companies Mannesmann-Meer A.G. and Maschinenfabrik Karl Wittig G.m.b.H. Mannesmann-Meer displayed models of single- and double-stage compressor installations, including a four-cylinder machine delivering 1500 Nm^3/hr at 9 atm. Steam-driven horizontal compressors, similarly shown, were six-stage machines capable of compressing 3600 Nm^3/hr to 180 atm, while other models included opposed-cylinder compressors with capacities as high-pressure machines of 2000-9000 Nm^3/hr; steam-compressors, oxygen-compressors and machines for supplying oil-free gases under pressure were also depicted.

Wittig turbo-compressors, which were also to be seen, can be supplied as single or two stages with dual flow, capable of compressing 4000-20,000 Nm^3/hr to 3 atm in a single stage and from 4000-10,000 Nm^3/hr to 9 atm in two stages. One such compressor with a rotational speed of 25,500 rpm compressing 8100 Nm^3/hr, by a ratio of 3, requires 397 kW, with adiabatic efficiencies approaching 80 per cent.

66.074.7

THE DOWNCOMER DESIGN IN CONTINUOUS PLATE ADSORBERS

THE continuous conveyance of adsorbent in continuous adsorbers from one plate to the plate beneath and the maintenance of a constant level of a "boiling" layer on the plate are the main conditions which have to be observed in downflow adsorption processes. As in the case of distillation columns, the fluidised solid stream can be transferred from one plate to the plate beneath by means of tubular downcomers. One important application of this principle has been in those parts of the Wisconsin process plant which recover dilute oxides of nitrogen, an operation carried out by means of a fluidised system of silica gel particles.[1] Little attention has been given in the literature, however, to such considerations of downcomer design as their sizing and methods of controlling discharge rates of streams of fluidised particles.

According to I. F. ZEMSKOV,[2] a downflow apparatus with a conical restriction at the base of the tube has proved effective for regulating large flows of small particulate solids; for instance, powdered talc and silica gel, with grains of a few microns in size 1-3. This, however, is of little use for the transference of materials of large particle sizes; for instance, activated carbon, with grains of 2-5 mm and greater. This is particularly so when the quantity of adsorbent added is comparatively small, and where the specific weight of the latter changes sharply in the process of adsorption. For example, in the process of adsorbing organo-metallic compounds, the specific gravity of the sorbent almost doubles. The use of adsorbents under industrial conditions with such "downflow" equipment is not made easier by the use of adjustable annular devices.

In his paper on the Wisconsin process ERMENC[1] refers to downcomers which are fitted with a special spring unloading device, but does not give details.

He does, however, give a number of dimensions worth noting. For example, in the combined adsorber and regenerator for the NO containing process stream and for regenerating the adsorbent, a flow of 80 lb/min of gel is transferred through four 5-in.-bore downcomers. Transference of the gel from the drying to the regeneration section was through a 6-in.-bore pipe, at the end of which was fitted a proportioning valve controlled by the pressure drop across the bubble-cap plate of the adsorbing section. The column, which was 10 ft in diameter and approximately 70 ft tall, contained seven perforated plates plus a single bubble-cap entrance plate in the adsorbing section. The perforated plates had holes of $\frac{3}{16}$ in. diam. to give a 13% free area, the gel was of 6-12 mesh particles, and the superficial velocity in the column was 4.5 ft/sec.

In the case of the NO_2 adsorber, however, the dimensions and details differ in some respects from those of the adsorber-drier. Its diameter was 10 ft and its height 92 ft, inclusive of the regenerator section. Twenty-one perforated plates and one bubble-cap distributor plate were employed. Since the total gel flow was 600 lb/min, 24 downcomers per plate were employed instead of the four used in the drier-adsorber, and transference from adsorber to regenerator (for liberating NO_2) was by means of six 3-in.-bore pipes. The free area provided by the perforations was again 13%.

Downflow tubes with intermittent discharge of the adsorbent were also mentioned by ZEMSKOV (Fig. 2). According to this design, each downflow tube is fitted with an upper and lower non-return valve, connected in such a way that when one opens the other closes. The upper valve is closed by a lever; the lower valve opens and the contents of the tube are discharged on to the lower plate. But he considers this to be a clumsy and unreliable means of transferring the adsorbent.

ZEMSKOV carried out tests on the adsorption of pairs of organo-metallic compounds upon activated carbon of

Table 1

The effect of the Air-flow Rate and the Activated Carbon Particle Size on the Maximum Carbon Flow Rate

v in m/sec	h_l in mm	h_f in mm	H_b in mm	v_s in m/sec	v in m/sec	h_l in mm	h_f in mm	H_b in mm	v_s in m/sec
AR-3 technical					Fraction 2 mm				
1.3	65	90	170	0.244	2.5	30	65	—	1.834
1.66	65	—	190	0.380	2.0	35	60	220	1.71
2.0	65	—	190	0.795	1.5	35	60	150	0.991
2.2	30	45	170	0.783	1.0	35	60	135	0.122
2.5	30	60	210	0.917					
Fraction 1 mm					Fraction 3 mm				
1.1	35	55	140	1.1	2.5	30	60	190	0.893
1.55	33	60	—	2.04	2.0	40	60	170	0.649
2.0	30	60	Spouting effect from the tube	2.52	1.5	43	55	165	0.208
					1.0	43	43	—	—
2.5	—	—	—	—					

Notes: v = the air velocity in the column; h_l = the height of the stationary layer on the plate; h_f = the height of the boiling layer on the plate; H_b = the height of the boiling layer in the tube; v_s = the maximum speed of downflow of adsorbent from plate to plate (equal to the input rate of sorbent from the measuring tank).

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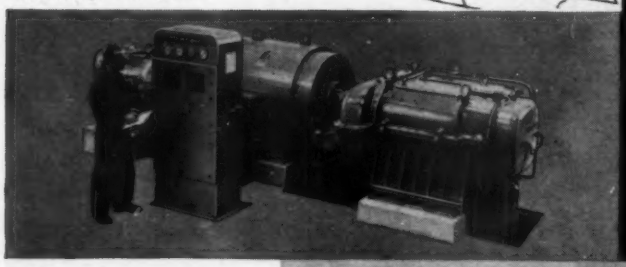
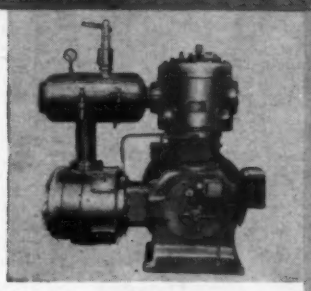
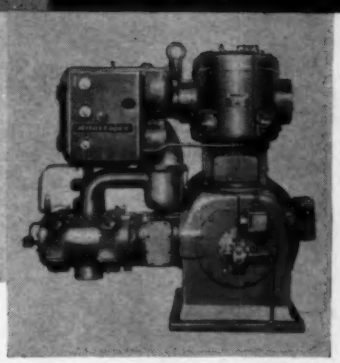


Twin-Air Rotary Screw Compressor

ER6 Compressor



AA-type low pressure Compressor



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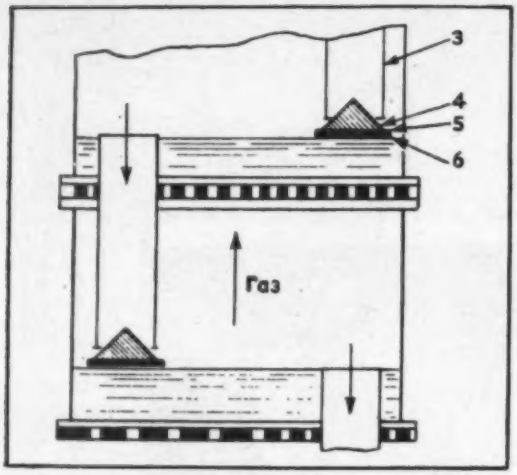

Fig. 1. A diagram of the column with a conical closure device.

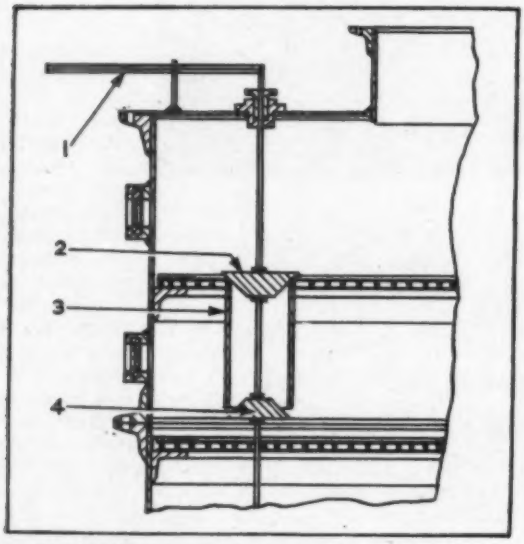

Fig. 2. A diagram of the column with volumetric downflow apparatus: 1, lever; 2, upper valve; 3, downflow tubes; 4, lower valve.

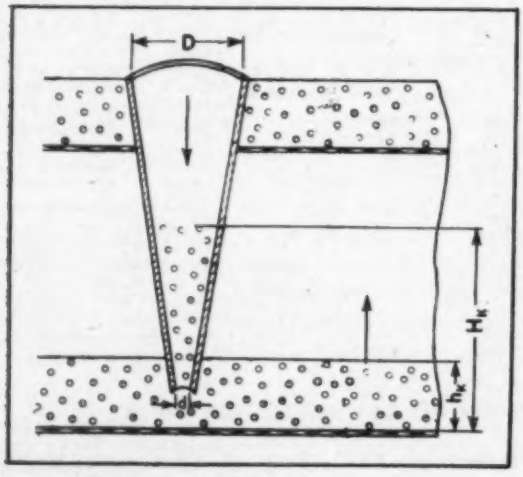

Fig. 3. Conical downflow tubes: 1, upper tray; 2, lower tray.

particles of 1-5 mm in a continuously operating multistage column with "boiling" layers, fitted with conical, hollow, downflow tubes (Fig. 3) which were stated to operate reliably. The tubes were arranged vertically between the plates of the apparatus, with their wider ends set at the level of the "boiling" adsorbent of the upper plate; and with the narrower ends submerged in the layer of adsorbent on the plate beneath, at a distance 25-40 mm from the plate surface.

The principle of operation of the conical downcomer is as follows. As the gas flow ascends the tube, its velocity diminishes, and in the upper section becomes considerably less than the critical. In operation, some of the adsorbent is removed by the gas to a point near the top of the tube; it does not, however, leave the tube, but remains at a height where the velocity of the gas corresponds to the speed at which the particles are "floating". Because of the "floating" particles extra resistance is set up (which increases with the number of particles), and this lowers the gas velocity in the tube. When there is a definite layer of "floating" particles, the resistance to the gas flow at the narrow end of the tube approaches the resistance of the gas at the plate, so that the system is in equilibrium. The "floating" part of the adsorbent in the tube will prevent the gas from "jumping across" without purification when it passes through the downflow tube.

When a fresh portion of adsorbent is added, the surplus falls into the downflow tube and destroys the equilibrium of the "floating" layer. In order to restore the balance, the surplus will fall to the plate below; the "overflow" tubes are therefore automatic in operation.

When the adsorber is stopped the "floating" layer falls to the lower plate, and is drawn through the narrow opening projecting into the layer of adsorbent when the column is again operating. The "floating" layer is thus returned to the downflow tube. In determining the diameter of the narrow lower opening, the chief consideration is to provide a free passage of adsorbent; this requires that the lower opening should have a diameter equal to not less than 5-6 times the size of the largest particles of adsorbent.

So that the latter may freely enter the upper opening of the tube, it is necessary that the velocity in it should be lower than that corresponding to the onset of fluidisation for a given adsorbent. On the basis of his tests ZEMSKOV recommends that the velocity at the upper open end should be 0.3-0.5 of the onset-of-fluidisation velocity, i.e., $= 0.3\text{-}0.5\ v_{crit.}$

Let the superficial gas velocity in the apparatus in the presence of adsorbent be v m/sec; then the gas velocity in the lower aperture of the pipe in the absence of adsorbent will be

$$\Sigma v = v_0 + v$$

where v_0 is the extra velocity arising from the absence of adsorbent in the tube and from the presence of the adsorbent layer on the plate.

If the resistance $\triangle p$ of the layer of adsorbent is known (this is readily measured), then

$$v_0 = \frac{2.25}{k}\left(\frac{10\triangle p}{\rho}\right)^{\frac{1}{2}} \text{ m/sec.}$$

where $\triangle p$ is the resistance of the adsorbent layer in metres H_2O; ρ is the density of the gas in kg/m^3; and k is a coefficient close to unity which takes account of the resistance to the gas-flow in the pipe.

Given the gas velocity in the upper section of the tube (e.g., $v = 0.4\ v_{crit}$) and the diameter at the lower end, which is dependent on the diameter d_0 of the particles of the adsorbent (for instance $d = 6d_0$), the following equation can be obtained for the diameter at the top of the tube:

$$\frac{D^2}{d^2} = \frac{\Sigma v}{0.4 v_{crit}}$$

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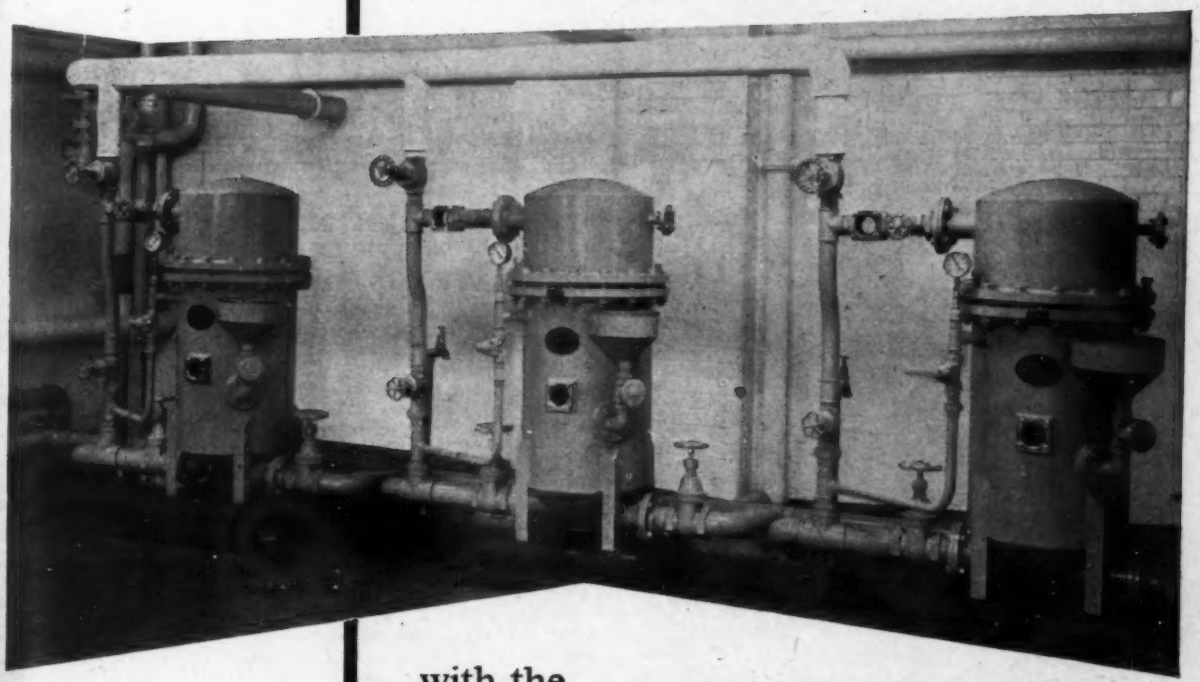

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whence $$D = d\left(\frac{v_0 + v}{0.4v_{crit}}\right)^{\frac{1}{3}}$$

Usually $D = 3d$. The required number of downflow tubes for each tray is determined from

$$n = w/\rho AN$$

where w is the quantity of adsorbent conveyed from one tray to the one beneath, in kg/hr; ρ is the density of adsorbent in kg/litre; $A = 0.785\ d^2$ less the cross-sectional area of the lower opening in cm². N is the permissible load of adsorbent, without flooding, for the lower section of the tube (in litres/cm² hr). For one type of Russian activated carbon (type AR-3,) with a gas-flow rate of 1-1.5 m/sec, ZEMSKOV states that the value of N should not exceed 25 litre/cm² hr.

He investigated maximum load and "flooding" in conical pipes by means of the apparatus shown in Fig. 4. This consisted of three hollow, vertically-arranged chambers of glass, 160 mm in diameter and 420 mm in height. As in adsorption columns, perforated gas-distributing plates were placed between the chambers, with wire-mesh stretched upon them, for supporting the activated carbon.

Downflow tubes, $D = 76$ mm and $d = 25$ mm, were arranged, one per plate at a uniform height, with a 25-30-mm gap between the narrow end of the tube and the tray. The lower downflow tube led from the column to the exterior to permit withdrawal of the adsorbent from the system.

"Boiling" layers on the trays were established by introducing air into the column, and by feeding granular material from the measuring tank (Fig. 4) to the upper plate at a point remote from the downcomer. The charge consisted of activated carbon particles (type AR-3) of 1, 2 and 3 mm in size and the ratio of the diameter of the narrow end of the tube, d, to the diameter of the particles, d_0, of the material was 25, 12.5 and 8 respectively.

The height of the entire "moving" layer in the tube ("boiling" and "floating") is considerably greater than the height of the boiling layer on the tray.

Tests were carried out with air velocities based upon the empty column of $v = 1.0$, 1.5, 2.0, 2.5 m/sec, which were lower than the speed of removal v_{rem} for the experimental type of granular material. Experimental values of v_{crit} are given below.

Size of particles in mm	v_{crit} in m/sec
Technical activated carbon (70% of the particles were 3 mm in size)	1.1
3	1.4
2	0.9
1	0.5

Before starting a run in this apparatus, activated carbon was spread over the plate to the level of the top of the downflow tube; air was then fed through the column to bring the carbon to the "boiling" state.

By increasing the rate of adding the granular material from the measuring tank to the plate, for a fixed velocity, the author found the maximum throughput for the tube, and the "flooding" point, at which the quantity of adsorbent added exceeded the discharge capacity of the downflow tube. It is evident that the "floating" and "boiling" layer conditions in the tube, especially when the granular material is uniform, are not sharply defined.

When the gas velocity in the column approaches that at which the solid material is carried over, the borderline between the "boiling" and "floating" layers in the tube becomes considerably less clear.

As can be seen from the table and Fig. 5, a superficial velocity in the column lower than the carry-over velocity, and the use of smaller particles, gives an increase in the discharge capacity of the downflow tube (with a maximum speed of flow of v_3). The same also occurs when the superficial air velocity in the column increases.

The results of the tests, which are shown in the table, were obtained under conditions where there was a 25-30-mm gap between the narrow end of the "downflow" tube and the tray. If the size of this gap is increased or the tube is raised above the "boiling" layer on the tray, the value of v must be increased.

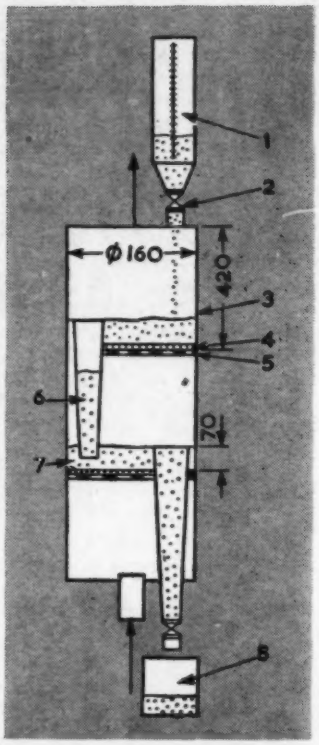


Fig. 4. A diagram of the equipment for determining flooding of a downflow tube: 1, the measuring tank for active carbon; 2, faucet; 3, chamber; 4, wire-mesh; 5, grill; 6, downflow tube; 7, activated carbon; 8, receptacle for pouring carbon.

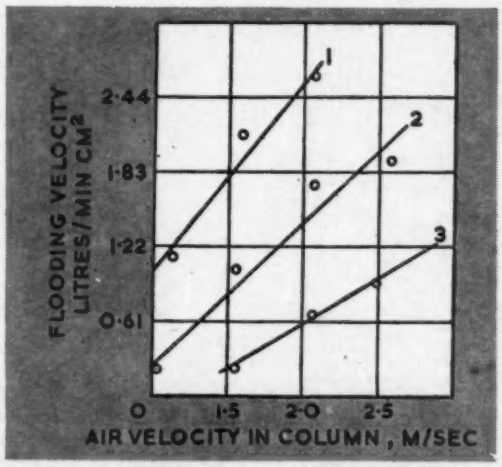
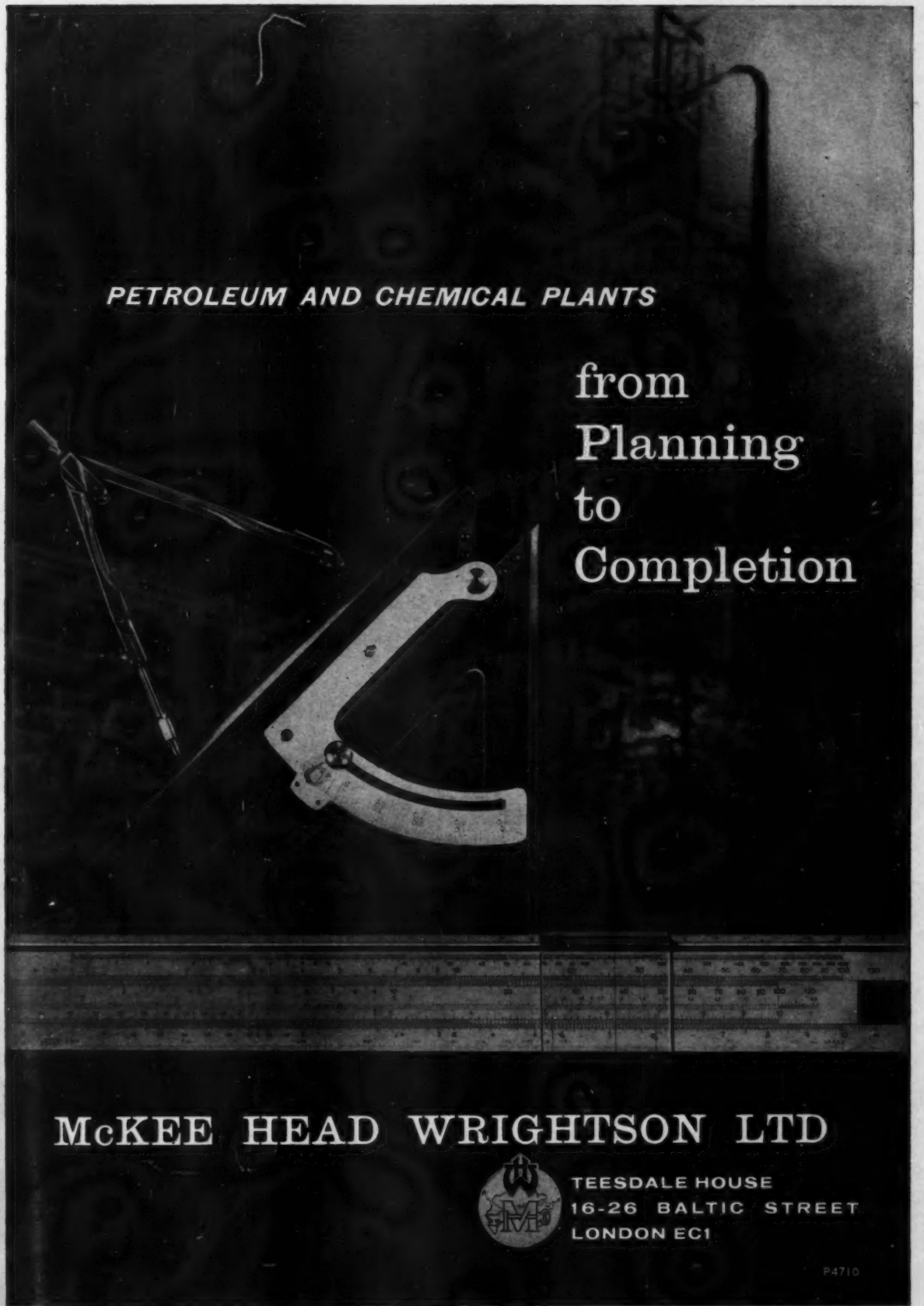


Fig. 5. The dependence of flooding velocity in downflow tube upon the linear air velocity in the column, and the carbon particle size (the lower end of the downflow tube has a diameter of 25 mm): 1, for particles of 1 mm in size; 2, for particles of 2 mm in size; 3, for particles of 3 mm in size.

REFERENCES

[1] E. D. Ermenc, *Chem. Eng. Prog.*, 1956, **52**, 11, 488.

[2] I. F. Zemskov, *Khim. Mash.*, 1960, **2**, 4.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STAINLESS STEEL USED IN HOLLAND'S FIRST CARBON BLACK FACTORY

by J. GRINDROD

AT the end of April 1960 the first Dutch carbon black factory was started up in the Botlek area near Rotterdam by Ketjen Carbon N.V., an enterprise established by the Koninklijke Zwavelzuurfabrieken v/h. Ketjen N.V., Amsterdam, and Godfrey L. Cabot Inc., in the U.S.A., the largest carbon black producer in the world. With this plant, Ketjen Carbon N.V. also became the first major carbon black producer in the Benelux. Until recently, practically all the carbon black consumed by the tyre manufacturers in this area had to be imported mainly from the United Kingdom, Germany and the U.S.A. Now that the Common Market has become a fact, this is likely in due course to alter the import picture.

The new plant is the first of the Ketjen family which is not located in Amsterdam. The Botlek area offered special facilities in the way of transportation of raw materials and products, from overseas as well as from and to the hinterland and as an on-the-spot source of raw materials and intermediates for further processing from the three large refineries at Pernis with a total capacity of more than 500,000 barrels per day.

Capable of producing initially 24,000 tons of carbon black products a year, more than half of which is intended for export, the plant has so far concentrated on the production of High Abrasion Furnace (HAF), Intermediate Super Abrasion Furnace (ISAF), Fast Extruding Furnace (FEF), General Purpose Furnace (GPF) Semi-Reinforcing Furnace (SRF), Channel Replacement (CR), Low Hardness ISAF (LHI) with the physical and chemical characteristics shown in the table on page 880.

The raw materials required for the production of furnace blacks—gas and oil—are supplied both from the Pernis refineries and by tanker from overseas, and the mixture of heated oil and gas is decomposed into carbon black and gas in the furnaces, which are carefully controlled to produce the type and quality of black desired by varying temperatures and the addition of air.

From the furnaces, the black-laden gas stream, after being cooled, is conveyed to the cyclone collectors, which are of the latest design to give a very high rate of carbon black recovery. In contrast to the usual practice in carbon black plant construction and, as a result of Ketjen's experience in chemical engineering, most of the plant is lined with or made of stainless steel. This has the desirable result that the end products have a much lower grit content than would otherwise have been possible. This purity, coupled with the

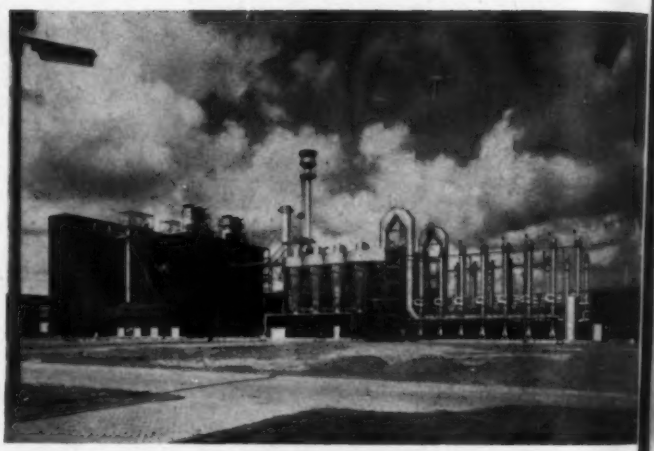

Fig. 1. Unit No. 2 at the new Ketjen carbon black plant, Botlek area, Rotterdam, Holland.

Fig. 2. Aerial view of the Ketjen plant showing the two production units, storage tanks and processing building.

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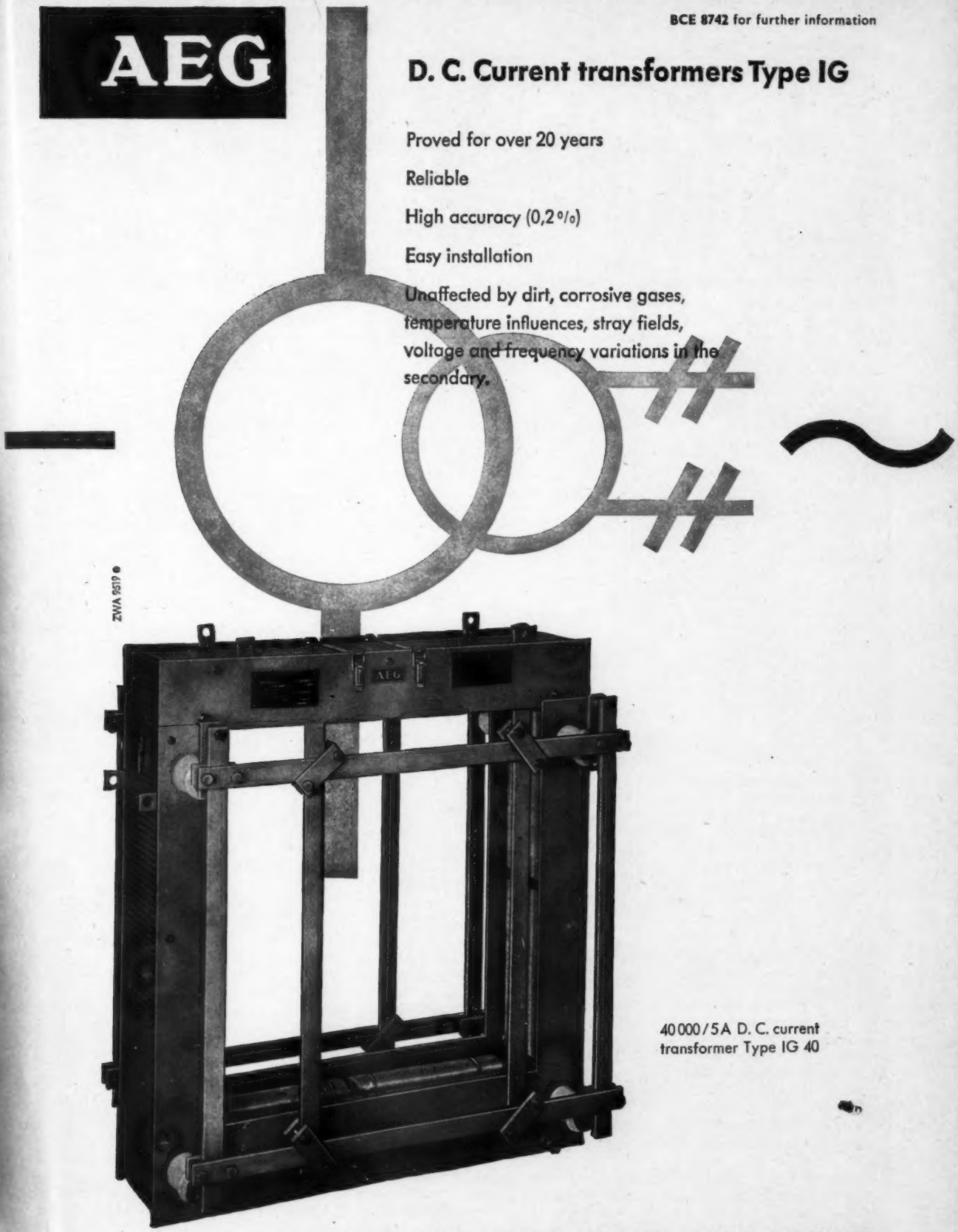

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KETJENBLACK	ISAF	LHI	HAF	CR	FEF	GPF	SRF
Nigrometer value	89	88	91	89	94	97	95
Tinting strength	230	230	220	220	125	105	120
Photrometer value	97	98	95	99	97	96	95
Benzene extraction, %	0.05	0.05	0.05	0.05	0.05	0.05	0.05
BET surface, m^2/g	115	116	79	78	42	34	34
Electr. micr. surface, m^2/g	102	90	92	91	57	47	39
pH	8.5	9.0	9.0	9.0	8.5	8.5	7.5
Moisture, %	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Volatile matter, %	2	1.5	1.5	1.5	1.5	1.5	1.5
Ash, %	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
325 mesh residue, %	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
Cu, %	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Mn, %	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Fe, %	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Apparent bulk density, kg/dm^3	0.37	0.43	0.37	0.40	0.37	0.40	0.50

rigid control exercised throughout the process, yields a uniformly high quality.

From the cyclones, the gas stream with the remaining small percentage of carbon black passes through filter bags, where the rest of the carbon black is collected. The gas stream is then utilised in the boiler house, the unwanted portion being flared so as not to pollute the air. Pneumatic conveyors transport the collected carbon black to the processing building where, after separation from the air stream, the agglomerated particles are first pulverised and then partially densified into fine, uniform, round pellets of good structural strength and stability. Product samples are regularly tested for quality in the adjoining plant laboratory.

Such is the freedom from smoke output at the new plant that the outside of the building incorporates a considerable quantity of aluminium, and there is no fear of it becoming too blackened. A similar cleanliness is an indoor feature of the plant where dust control is emphasised.

New or improved packing and transportation systems are also a feature of the Ketjen plant, where it has been possible to draw on the Dutch company's already extensive experience. Installations for receiving and conveying blacks to internal mixers are worked out in close co-operation with the consumer so that a system can be specially adopted to the conditions at the customer's plant.

For the dispatch of 25-kg (or 50-lb) units four-ply paper bags are used, colour coded according to product. Bulk orders are delivered by means of a Tilt-O-Can system which involves the use of a 1-ton aluminium container which can be discharged with the aid of a simple unloading device. Rectangular in shape, the container has a filling hole in the top corner and a discharge opening in the bottom corner diagonally opposite. These two openings are positioned in such a way as to obtain a maximum content in an inclined position and a minimum of opening space during discharge. Notwithstanding its light weight of 80 kg, the Tilt-O-Can is of very rugged construction and incorporates V-shaped reinforcements in its four walls. Since the Tilt-O-Can is weather-proofed and protected against corrosion, no warehouse is required to store the carbon black and this will enable expanding rubber companies to use their warehouse space for other purposes. Floor space can be reduced by piling three containers on top of each other.

Bulk transport by tank trucks or railway tank-cars also saves handling costs, though this involves special unloading facilities at the customer's plant.

Computers in Chemical Engineering

A MEETING of the Institution of Chemical Engineers, North-Western Branch, was held at Manchester on October 25, when a paper, "Computers and their Application in Chemical Engineering", was presented by Messrs. D. W. HOLMAN and J. J. SETTLE. The authors discussed the way in which a computer is instructed to carry out a calculation and the solutions of several chemical engineering problems. This summary of their paper presents a brief outline of most of the practical steps necessary to solve a problem.

Computers will carry out step by step any sequence of calculations which is specified to them; they cannot detect errors and, if the computer makes an error, it is usually a big one and easily detected. It is wrong to think that computers are suitable for use only on problems of which the solutions require many man-years of work, also that much money and effort are necessary to solve these problems. Many mathematicians, physicists, chemists, engineers and statisticians are engaged in preparing programmes for computers, not as a full-time job, but as part of their normal occupations.

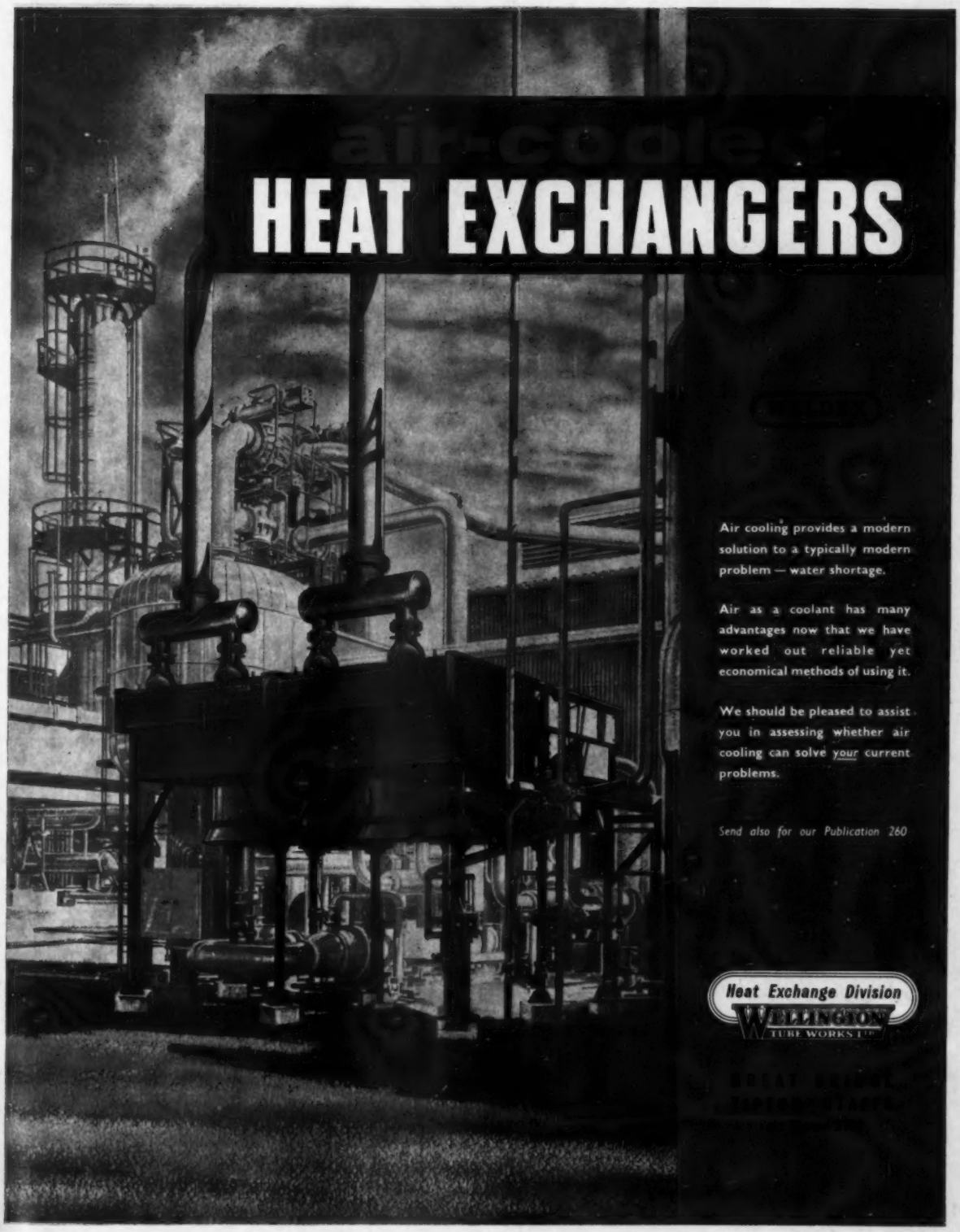
The authors stated the steps necessary to solve by computer a quadratic equation $y = a + bx + cx^2$. This equation is factorised $y = (cx + b)x + a$; the best way to obtain y is multiply c by x, add b, multiply by x and add a. A programme is written for the computer to perform this series of operations and it must be written in a code the computer can understand; for example, 210, c means put c into the accumulator which is the part of the computer where calculations are made, 212, x means multiply x by the number in the accumulator, 211, b means add b to the number cx now in the accumulator, 212, x means multiply x by the number obtained by the last operation and 212, a means add a to obtain a value for y which is punched out when the computer receives the order 208,0. Numerical values for a, b, c and x are fed into the computer by means of a punched tape or punched cards. The computer has a device for reading each combination of holes or no holes and each number is stored in a "memory".

Today it is not necessary for the programmer to learn the very complex instruction language of his computer because many computers have autocodes that are easy to learn and are essentially algebra and English. These autocodes enable any chemist or engineer to learn in two days how to construct a programme.

Thus, to use a computer a precise knowledge of the calculation is necessary, a step-by-step programme must be written and careful thought is required to apply the knowledge of programme construction.

The value of approximate methods for the calculation of distillation columns for multi-component mixtures is that changes in the data can be made, and the effect of the changes in quantities and purities of the distillate of each component can be quickly determined on the computer. Twenty runs of twenty seconds each on the computer will serve to show the economics of demanding excessive purities.

The authors discussed some specific problems and some difficulties met during work with computers.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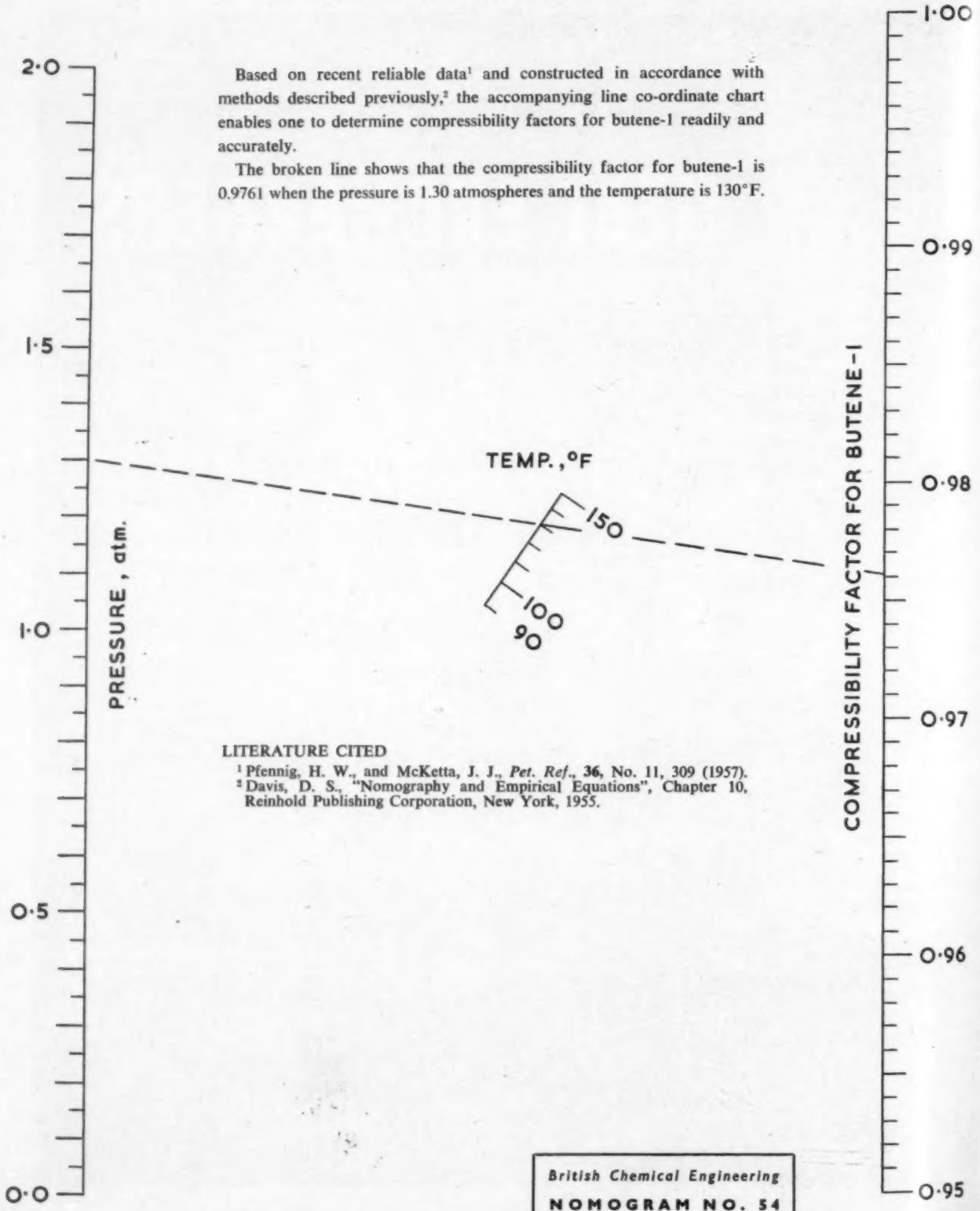
NOMOGRAM SHOWING COMPRESSIBILITY FACTORS FOR BUTENE-1

by D. S. DAVIS

(Head, Department of Paper and Pulp Technology, University of Alabama)

Based on recent reliable data[1] and constructed in accordance with methods described previously,[2] the accompanying line co-ordinate chart enables one to determine compressibility factors for butene-1 readily and accurately.

The broken line shows that the compressibility factor for butene-1 is 0.9761 when the pressure is 1.30 atmospheres and the temperature is 130°F.



LITERATURE CITED

[1] Pfennig, H. W., and McKetta, J. J., *Pet. Ref.*, **36**, No. 11, 309 (1957).
[2] Davis, D. S., "Nomography and Empirical Equations", Chapter 10, Reinhold Publishing Corporation, New York, 1955.

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PROCESS ENGINEER'S NOTEBOOK

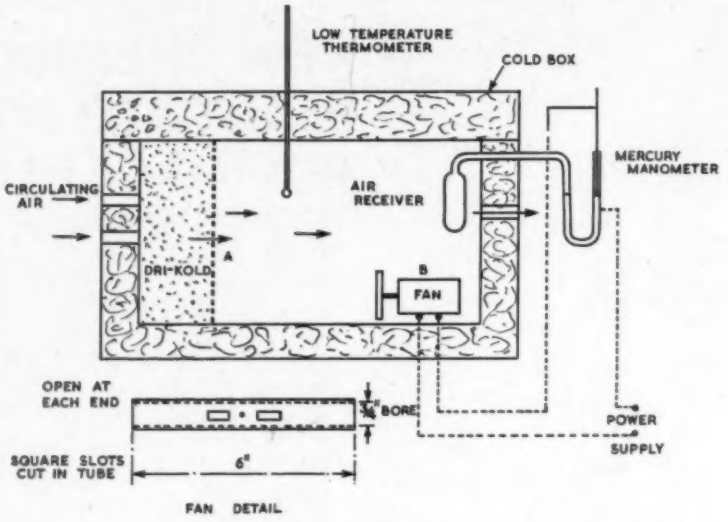
"Cold Box"

THE DEVICE DESCRIBED below may be used when it is desired to make measurements at low temperatures of such properties as viscosities, etc. It is easily made and quite cheap.

The cold box is shown in diagram and consists of an inner and outer box; the space between each is filled with kapok or other insulating material. A is a piece of expanded metal the same width as the inner box and extending from the bottom to the top. B is a fractional-h.p. motor with a fan device fixed on the shaft. The fan device shown in detail consists merely of a ¼-in-bore tube about 6 in. long, open at both ends and having two square slots cut in the tube wall near its centre.

To obtain a low temperature the space between the expanded metal sheet and the side of the cold box is filled with "Dri-Kold" (solid CO_2) and the motor is switched on. This pulls a current of air through the Dri-Kold, thus cooling the space within the box.

When the desired temperature is attained it can be held constant by switching the motor "on and off'. This can be done automatically by incorporating the thermostatic device as shown. This consists of a mercury manometer connected to an air receiver within the top by a piece of pressure tubing. A small-diameter metal rod projects down one limb of the manometer and can make contact with the mercury. A piece of wire is fused out from the limb of the U tube in such a way that it is always in contact with the mercury. The metal rod and the wire are connected in series with the motor and power supply. The device thus acts as a switch.

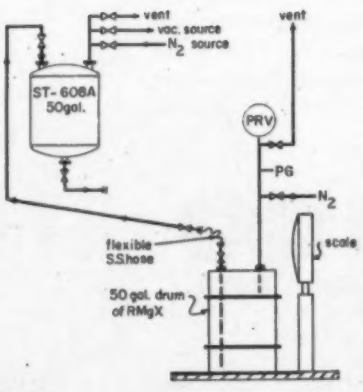


When the temperature in the box rises, the air expands and pushes up the mercury in the U tube, contact is made and the motor is switched on. On the other hand, when the temperature falls the air contracts and separates the mercury from the rod, contact is broken and the motor switched off.

The desired temperature in the box can be pre-selected by lowering or raising the rod relative to the level of the mercury.

R.H.U.

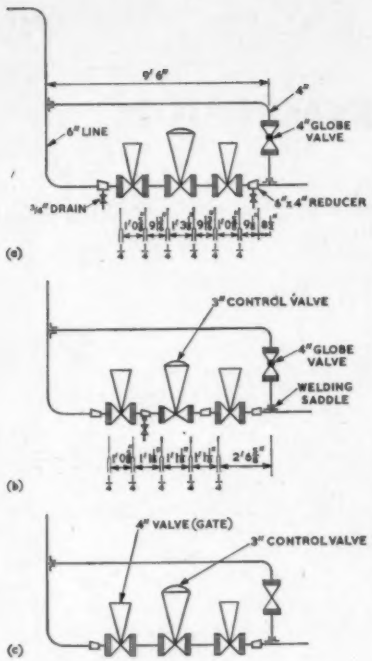
Charging a Grignard Reactor



IN THE PREPARATION of dimethyl cadmium by means of a Grignard reaction, a safe method of adding the Grignard reagent to the reaction system was required. The diagram shows the method by which this was carried out.

Welded connections were made to the 40-gallon drum in the manner shown. The full drum, resting upon the scale platform, has the vent and nitrogen lines connected initially. The large bung is removed and a nitrogen purge lasting 5 minutes is started. When the pumping operation is complete, the charge line is inserted and connected to the previously dried still (ST 608A) which, in addition, had been purged of air by applying vacuum and by venting three times with nitrogen. In readiness for the transference, the still was put under a 20-in. vacuum and the drum under a nitrogen pressure of 2 psig. The charge valves were next opened to allow the required weight of reagent to be transferred from the drum. This included 8 lb of line hold-up. This done, the valve at the still was closed, the nitrogen supply interrupted and the drum vented. This allowed the 8 lb of hold-up to be returned to the drum. In readiness for the next batch, all the valves were closed and a positive pressure of 1 psig of nitrogen applied to the drum.

Abstracted from "Organic Pilot-plant Operations", P. G. Colin and J. Gillin, *Chemical Engineering Progress*, 74, September 1960.



Pipeline Modification for Control Valve

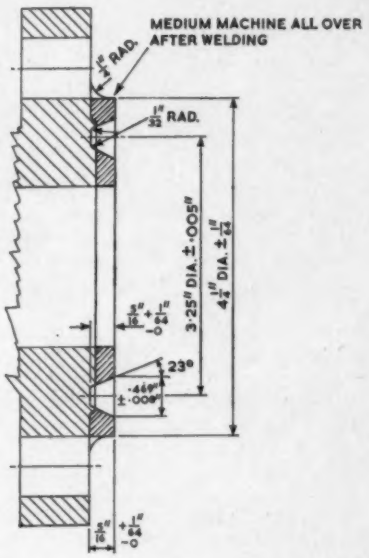
THIS SKETCH SHOWS how it became necessary to modify a drawing because of delivery delays for a control valve; sketch "(a)" shows original proposed arrangement with a 4 in. control valve. Because of delivery delays it was necessary to use an existing 3 in. control valve temporarily, as shown in sketch "(b)". When the 4 in. valve arrived it was installed as in sketch "(c)" during plant operations of a continuously operating plant. The sketches illustrate the fact that a control valve assembly should always be designed to permit the installation of maximum sized valve even though a smaller valve might be sufficient for present requirements.

K.J.G.

Valve Joint Conversion

THE ATTACHED SKETCH shows how a second stainless steel 300 flange with raised face was converted to the octagonal ring type by building up with weld metal and machining. The operation became necessary because of long delivery for O.R.J. flanges.

K.J.G.

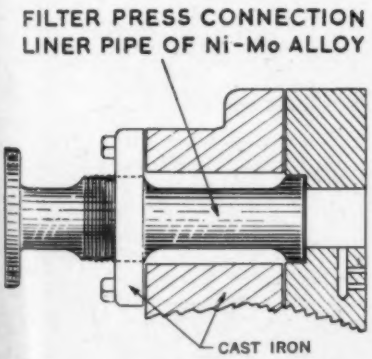


Nickel Molybdenum Alloys for Filter Presses

FILTER PRESSES for separating precipitates from corrosive liquids usually require the use of highly corrosion-resistant alloys in their construction. In some recently reported examples of filter presses used for such duties* the liquid phase was an organic solvent at 93°C containing sulphuric acid; hot hydrochloric acid solutions were also handled in some of the presses.

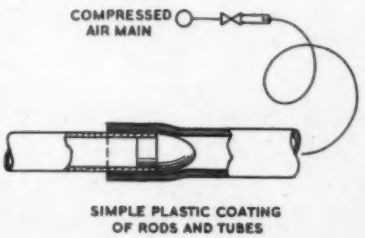
Liner parts cast from either a 65 Ni-30 Mo-5 Fe or a 59 Ni/17 Mo-5 Fe-14 Cr alloy were used for the feed and discharge connections, and the side members supporting the plates and frames were protected from the corrosive liquors by means of folded sheets of the second alloys.

* *Haynes Alloys Digest*, 1960, 9, 3.



Simple Plastic Coating of Rods and Tubes

IT IS FREQUENTLY necessary to plastic-coat rods and tubes as a protection against abrasive and corrosive chemicals; in the instance referred to, for example, it was required to cover ¼-in.



SIMPLE PLASTIC COATING OF RODS AND TUBES

M.S. rod with a heavy polythene coating. The quickest and cheapest method of doing this was to insert the rod into ¼-in.-bore heavy-walled unplasticised polythene tube so as to provide an interference fit. This was found easy to accomplish if the polythene tube was connected at one end to the compressed air main and the rod inserted in the other end. The air was then switched on and the rod floated into the tube on the flowing film of air.

A similar method can be used for covering tube, but it is then necessary to plug the entry end with a parabolic profiled plug as indicated on the sketch.

F. MOLYNEUX

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

AUSTRALIAN FLUIDISATION SYMPOSIUM

IN mid-February 1961, the Chemical Engineering Group of the Royal Australian Chemical Institute are presenting a series of papers devoted to fluidisation, and so far ten papers covering various aspects of this operation have been arranged, the titles, authors and synopses being given below.

"Fluidisation in Shallow Beds—Multistage Fluid Bed Drying"

This paper deals with the problems of fluidisation peculiar to shallow beds and describes the development of a high-efficiency, multistage, fluidised-bed drier suited to the drying of materials containing occluded or bound moisture.

"The Application of Fluidisation for Heat Transfer"

This paper describes the development of an efficient gas-liquid heat exchanger using a fluidised bed to increase the rate of heat transfer. Both these papers will be delivered by members of the staff of Monsanto (Australia) Ltd.

"Some Problems Affecting the Carbonisation of Coal in a Fluidised Bed", by K. McG. Bowling and P. L. Waters, Coal Research Section, C.S.I.R.O.

The authors show that although the application of fluidised-bed technique to the low-temperature carbonisation of coal has overcome the problem of transferring heat rapidly to a large mass of coal, it has, however, introduced new operating problems, many of which are not usually encountered in other types of fluidised-bed processes. With coal, the main problems are: the tendency for coal particles to agglomerate and choke the reactor; the tendency for fine dust particles to be carried over into the condensing train and to contaminate the products; determining the best way of supplying the heat necessary for the carbonisation process. The authors describe operating experiences gained with a small experimental plant carbonising Australian coals, and how some of the above problems which arose during the course of this work were overcome.

"Determination of Particle Residence Time in a Fluidised Bed—Theoretical and Practical Aspects", by K. McG. Bowling, Coal Research Section, C.S.I.R.O.

The author emphasises the necessity for an estimate of the residence time of particles undergoing a change in a fluidised bed in order to characterise the reaction conditions. Because particles move at random in fluidised beds and their residence times are non-uniform, mean values of residence time are required and ways of determining such values are discussed.

The distribution of residence times occurring under various conditions in practice has been experimentally determined, and the results are compared with calculated mean values.

"Chlorination of Ilmenite (1). Design of Multistage Fluid Bed Reactors", by I. B. Ketteridge, Australian Mineral Development Laboratories

This paper presents an analytic treatment of multistage fluid bed reactors and a method of designing multistage reactors for reactions between particulate solids and fluids is outlined.

"Chlorination of Ilmenite (2). Practical Aspects of Design, Construction and Operation of Small-scale Fluid Bed Reactors", by A. W. Nordin, Australian Mineral Development Laboratories

Perspex models of 3-in. and 6-in. diameter multistage fluid bed reactors were constructed and used as a basis for the design of reactors of similar diameters constructed in fused silica for high temperatures. Problems in the construction and operation of the high-temperature reactors are discussed.

"Fluid Roasting of Zinc Plant Residues at Risdon, Tasmania", by O. G. Woodward, R. W. Pickering and A. R. Gordon, Electrolytic Zinc Company of Australasia Ltd.

Development and operation of a fluidised-bed roaster for the treatment of the product formed by reaction of ferritic zinc plant residue with sulphuric acid is described.

In the roasting process, ferric sulphate is decomposed and previously unreacted ferritic zinc is sulphated. Energy is supplied by the combustion of fuel oil within the bed.

"Fluidised-bed Roasting of Copper Concentrates", by R. W. Urie and A. B. Whitehead, Chemical Research Laboratories, C.S.I.R.O.

This paper will give details of an investigation of the fluidised-bed roasting of copper concentrates from the four major Australian copper mines, Mt. Morgan, Mt. Lyell, Mt. Isa and Peko. This work, which was sponsored by these mining companies, comprised the first stage of a comprehensive investigation of the application of the fluidised roast-leach-electrowinning process to copper metallurgy in Australia. Much of the work was performed in a 3 ft 6 in. diameter, slurry-fed, pilot-plant roaster operated under autogeneous conditions. Subsequently, a further series of roasting experiments was performed in a 12-in. diameter externally-heated roaster provided with a dry feed system.

An account will be given of important factors which influence roaster performance; design features of fluidised-bed reactors and auxiliary plant for copper concentrate roasting will also be discussed.

"The Influence of Solids Characteristics on the Performance of Fluidised-bed Reactors for Non-catalytic Operations", by A. B. Whitehead, Chemical Research Laboratories, C.S.I.R.O.

This paper will deal mainly with a number of problems of design and operation of fluidised-bed reactors which arise when a non-uniform solids feed is being continuously processed or when solids characteristics change in the course of processing. Factors influencing the choice of operating conditions in such circumstances will be discussed.

"The Sulphiding of Ilmenite in a Fluidised-bed Reactor", by A. B. Whitehead and C. J. Restarick, Chemical Research Laboratories, C.S.I.R.O.

An account will be given of a study of the reaction of ilmenite with sulphur vapour in the temperature range 600°-850° in a fluidised-bed reaction system. Severe sintering between particles occurs during the reaction and the means taken to obviate this will be described.

Full details of this symposium can be obtained from the Group Secretary.*

* F. R. Hartley, Australian Mineral Development Laboratories, Osman Place, West Thebarton, S. Australia.

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Book Reviews

Demineralisation by Electrodialysis
Edited by J. R. Wilson
Butterworths Scientific Publications, 378 pp. 60s.

THE book presents a detailed account of the experimental work which led the team of the National Chemical Research Laboratory of the South African Council for Scientific and Industrial Research at Pretoria, from the development of their ion-selective membranes, through the design and operation of experimental and pilot plant units, to the final production plant. This electrodialysis plant, at present the world's largest, reduces 100,000 gallons per hour from a salt content of 3000 p.p.m. to 500 p.p.m., thus converting brackish mine water into potable water. The book, which is well written, gives detailed accounts of all stages in the research, design, development and costing of the various plants, as well as of the difficulties in operation, and how these were overcome. While the technical and engineering parts form the backbone of the work, it is introduced by two valuable chapters dealing with the fundamental aspects of electrodialysis, first in a general and then in an exhaustive manner, leaving it to the reader how deeply he wishes to penetrate into the fundamental background based on more than a thousand scientific papers and patents quoted.

The book, which is well indexed, can be strongly recommended to all those who are interested in water treatment, as well as to students in applied electrochemistry and chemical engineering.

E. GLUECKAUF

Heat Transfer Engineering
by Hilbert Schenk
Longmans, 1960, 314 pp., 28s.

THE attention at present given to heat transfer is on such a scale that the subject no longer appears to be largely a collection of empirical data. Theoretical development has been so great that the subject can now fairly claim not only to be fundamental, but to be treated on a fundamental basis. The author of this volume of 314 pages is among the first, if not the first, clearly to convey this impression and to illustrate the importance of heat transfer in many technical fields, through some of the more recent advances in the subject.

Very moderately priced, the book deals in the first seven chapters both with steady and unsteady states. The three modes of heat transfer are considered separately and in combination. The final four chapters are given over to applications which include rocket propulsion and nuclear reactors, and to heat transfer testing. It is a pleasure to note that this is one of the very few American texts in which answers are provided to the well-formulated and realistic problems which are among its outstanding features.

The reviewer is of the opinion that this book will fill a long-felt need among engineering undergraduates for a satisfactory introductory text, while the unification of the subject which it achieves will make it of very considerable value to all those concerned with heat transfer.

B. W. MARTIN

Explosions, Detonations, Flammability and Ignition
by S. S. Penner and B. P. Mullins
Pergamon Press, 299 pp., 62s 6d. Published for the Advisory Group for Aeronautical Research and Development, North Atlantic Treaty Organisation.

THIS book is in two parts, written respectively by the two authors, and is intended to provide a summary of the existing knowledge of the subject up to the spring of 1958. Broadly speaking, the first part of the book is theoretical and the second part practical and thus Part 1 is a preliminary to Part 2. In Part 1 some knowledge of the classical work on the subject of the book is assumed, and the author has selected topics which are likely to be of lasting value. It is, in effect, a series of theoretical studies on combustion problems and the author has sought widely for his sources of information. Particular attention has been drawn to certain recent Russian work on the subject of chain reactions.

Part 2 consists of a critical review and correlation of the existing data of flammability and ignition. After discussing the flammability limits of fuel/oxidant mixtures and the factors affecting them, the authors discuss the limits of ternary mixtures of fuel/diluent/oxidant. A survey of the position regarding heterogeneous fuel/air mixtures follows. The next two chapters cover spark and spontaneous ignition respectively. The chapter on combustion processes refers almost entirely to engine combustion, so much so that one might regard the title of this chapter as slightly misleading, although it is a very interesting survey. The final chapters cover the general subject of explosion prevention and, here again, the emphasis is on engine test beds.

There is no doubt that this volume is an excellent review of the subject, but one feels that Part 2 is the more useful to the general chemical practitioner or, for that matter, the specialist in the subject-matter of the book. The list of references is much wider and this extra cover has been achieved without loss of quality.

British Standards

B.S. 3141: Part I: 1959. Master Schedule of Wrought Steels, Part 1: Carbon Steels, 10s.

DURING the many years in which the B.S.I. has been preparing specifications for steel, the tendency has been to publish separate specifications for different consuming industries such as aircraft, chemical and petroleum, and railway engineering. The effect of this has been to confront both consumer and manufacturer with an increasing number of specifications often only slightly dissimilar, thus adding to the difficulties of choosing and producing the most suitable steels. Consequently, at the request of the Iron and Steel Industry Standards Committee, a special sub-committee has carried out a comprehensive review of British Standards and Service specifications, and the present Part 1 of the co-ordinated schedule of properties and tests is deemed to cover the chemical compositions for carbon steels necessary to meet all normal requirements. The steels are set out on a basis of chemical composition, with mechanical properties included where appropriate.

B.S. 3161: 1960. Sizes of Process Vessels for Chemical and Allied Industries. 7s. 6d.

TYPES OF PROCESS vessel covered by this Standard are vertical cylindrical open, vertical or horizontal cylindrical closed, and so-called "boat" pans. Vessels of special shape, such as boiling pans with "foam curbs" and so on, are not included, nor are vessels of capacity greater than 5000 gal. Cast-iron steam-jacketed pans and cast-iron enamelled steam-jacketed pans up to 100 gal. capacity are also excluded and are dealt with in B.S. 186. Terms are defined and discussed in an attempt to overcome confusion on terminology. The object of this standard is to reduce the number of different dimensions as much as possible, so as to cut down the amount of press and other equipment required for fabrication.

Code of Practice for the Application of Aqueous Dispersions of Polytetrafluoroethylene to Metals, Ceramics and Glass. 2/-. Copyright Publication No. 43, The British Plastics Federation, London.

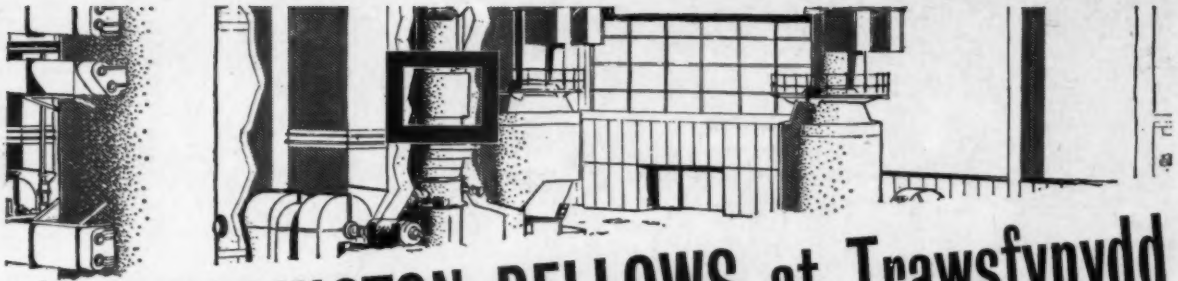
POLYTETRAFLUOROETHYLENE IS AVAILABLE in both powder form for moulding and extrusion and in a range of aqueous dispersions. Some of these dispersions are made especially for applying to metals and other surfaces which will withstand a processing temperature of around 400°C. These dispersions include primers and finishes, and it is this group to which the Code of Practice refers.

Taxation in Western Europe. A Guide for Industrialists, 1959. Federation of British Industries, London, S.W.1, 20s.

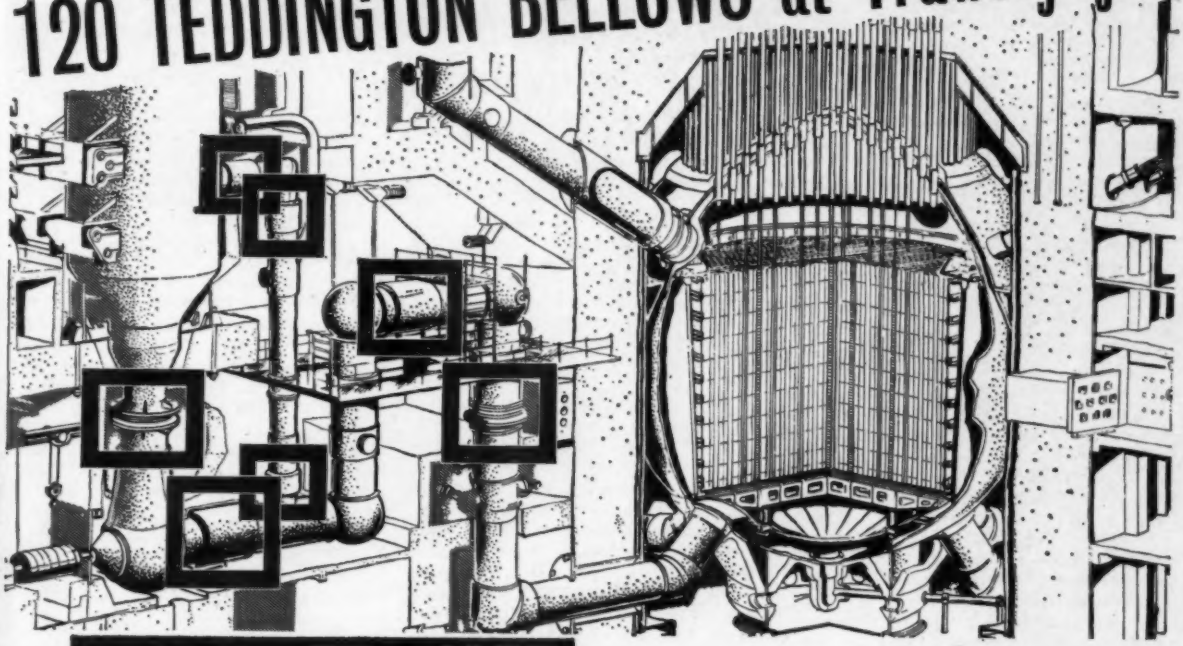
TO MEET A CONTINUING demand and to bring up to date the tax information about the countries covered, the Federation has decided to publish a third edition of a booklet on the title subject. The text describes the position as at July 1, 1959.

Seltene Naturstoffe 1959/60, Fluka A.G. Buchs SG Schweiz,

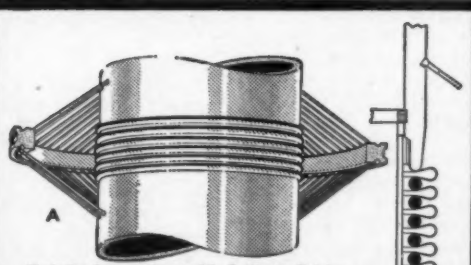
ALTHOUGH THIS IS primarily a classified list of rarer amino-acids, proteins, enzymes and so on obtainable from the publishing firm, the booklet has a supplement on paper-chromatography, R_F values, quantitative interpretation of paper chromatograms and allied subjects.



120 TEDDINGTON BELLOWS at Trawsfynydd



By courtesy of 'NUCLEAR POWER'



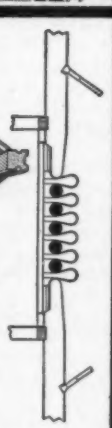


Illustration A represents one of the Teddington Stainless Steel Bellows supplied to Trawsfynydd with a novel form of restraint designed by Richardsons, Westgarth & Co. Ltd. (a member of Atomic Power Constructions Ltd.). This avoids the use of highly stressed hinge pins and permits a complete gimbal movement.

Illustration B indicates a section of Teddington Bellows, showing the restraining rings for extra strength which are a feature of this bellows design.

NO LESS THAN 84 BELLOWS 66″ diameter and 36 BELLOWS 42″ diameter, all of butt-welded stainless steel manufacture, are being fitted at Trawsfynydd to take up movement in the CO_2 cooling gas ducts.

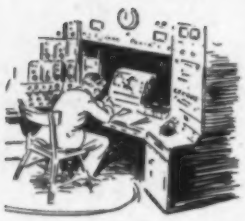
Teddington secured this order only after many exhaustive tests including an accelerated life test equivalent to 20 years full operation. In addition, the larger size bellows were subjected to over-pressure tests of 1580 p.s.i.g. without developing a leak. Wherever pipe-work is subjected to vibration and movement in any direction owing to conditions of temperature and pressure, a Teddington bellows with a suitable end fitting will solve the problem. Write for full details of our range.

TEDDINGTON AIRCRAFT CONTROLS LIMITED

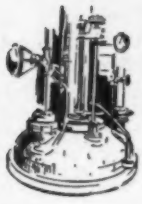
(INDUSTRIAL BELLOWS DIVISION),

AMMANFORD, CARMS.

Made under Licence from the Solar Aircraft Co. California, U.S.A.



LETTERS TO THE EDITOR



Support for Use of MKSA Units

Dear Sir,

In connection with the Editorial "Confusion on Units", page 541 of your August 1960 issue, your readers will no doubt recall that in a paper* delivered to the Institution of Chemical Engineers last year, a strong plea was made for unification of both units and dimensions.

Your move towards the MKSA system has my complete sympathy.

In the third paragraph of your article a distinction is made between pure science (world-wide usage of CGS system) and technology (development towards MKSA system). This could be read to mean that ultimately the two systems might be visualised to exist side by side in their respective fields.

I should, however, like to point out that the MKSA system is eminently suited for pure science as well. This is most strongly evident in the fields of electricity and magnetism where the MKSA system includes all of the practical electrical units.

Breaches have already been made in the universality of the use of the CGS system in pure science and in the teaching of physics. I have expressed the hope (see p. 340 of the paper referred to above) that it will disappear altogether.

Yours sincerely,

A. KLINKENBERG

's-Gravenhage,
Carel Van Bylandtlaan 30,
The Netherlands.

* "Principles of Selecting Dimensional Systems and Units in Chemical Engineering", A. Klinkenberg, *Trans. Inst. Chem. Eng.*, 1959, **37**, 335-41.

Discharge of Liquefied Petroleum Gases through Orifices

Dear Sir,

Your issue for April 1960 contains, on page 252, an article with the above title on which we should like to comment.

We are surprised to read that the authors have encountered very few papers on the subject. The flow of boiling water has in fact given rise to an extensive literature, going back to the experiments of Sauvage (1892). In more recent times notable contributions have been made by Bottomley (1936), Burnell (1946 and 1955), Benjamin and Miller (1941), Silver and Mitchell (1945) and many others. The flow of other liquids under similar conditions has been investigated by Pasqua (1953, dichlorodifluoromethane), Linge (1951, ammonia) and Förster (1955, carbon dioxide).

The reason for the adoption of Kitteredge and Dougherty's equation of flow is not clear, but it is clear why the authors' first theory leads to an unreal value for V_2. The equation (3) is not Bernoulli's equation for a compressible fluid, but merely the incompressible form with different densities at inlet and outlet inserted. Using the correct form, the authors' equation (6) would become:

$$\tfrac{1}{2}V_2^2 = -\int_1^2 \frac{dP}{\rho}$$

which gives a positive value for V_2. Because of the trouble in evaluating the integral graphically, other methods for determining V_2 are preferred and are described in the literature.

It is, however, well established that the observed flow of boiling liquids through orifices greatly exceeds the flow calculated on the basis of thermodynamic equilibrium at all stages. For a sharp-edged orifice the discharge is almost identical with that observed for the cold liquid, indicating that no appreciable vaporisation takes place in the orifice. For longer nozzles there is time for some vaporisation to take place, but not as much as that predicted by theory. Our own experiments using dichlorodifluoromethane have indicated that in a nozzle of $\frac{1}{16}$ in. diameter, $\frac{1}{4}$ in. long, the actual temperature drop in the liquid is about one-tenth of the saturation temperature drop.

We cannot see any justification for regarding equation (7) as a theoretical expression, the deductions from which are verified by the experimental results. At the best, it can only be regarded as an empirical equation which happens to relate two sets of experimental results.

Yours faithfully,

W. B. GOSNEY
W. H. EMERSON

Department of Mechanical Engineering,
King's College, University of London.

Engineer's Heat Bibliography

Dear Sir,

I appreciate the attention given in the September issue of *British Chemical Engineering* to the Heat Bibliography prepared by this Laboratory, and I should like to comment on your reviewer's criticism of the policy adopted in preparing it. We do not attempt to include all material published in a particular calendar year, as this would delay publication considerably; our experience shows that it may take a year or even longer to collect a complete list of references to papers appearing during a given period, particularly those from less accessible sources. For this reason, we simply draw a line at the end of each calendar year and prepare a list of the papers noted during that year. This is based on as complete a coverage as we can achieve, but it is obviously not complete as far as papers published *in that particular year* are concerned. Papers which are noted too late are included in the next edition of the Bibliography.

We believe that most users of the Bibliography prefer that it should be published in the present form rather than as a collection of references which attempts to be complete for a particular year but is very much out of date. Your readers may like to know that we are always pleased to supply lists of references *on specific subjects* noted since the publication of the latest Bibliography.

Yours faithfully,

A. J. EDE

Head of the Heat Division,
D.S.I.R. National Engineering Laboratory,
East Kilbride,
Glasgow.

Ferranti Argus Computer

Dear Sir,

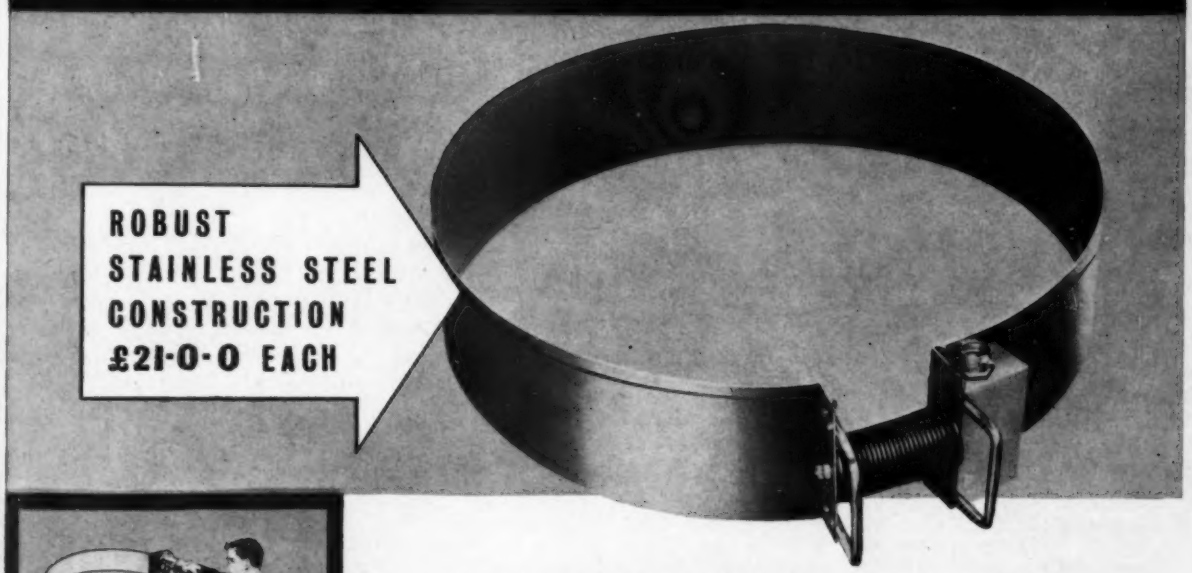
We appreciate the mention of the Ferranti Argus computer on page 111 of your February issue ("Trends in Process Control"), but feel that the last sentence may give a wrong impression of the capacity of an Argus computer control system. Argus is a fast digital computer desgned specifically for process control applications. It has a full range of peripheral equipment which can accept signals from conventional instruments on a plant and send signals back to control either the plant or its instrumentation. A variety of logging equipment is also available including printers, chart recorders, magnetic and paper tape, and visual displays.

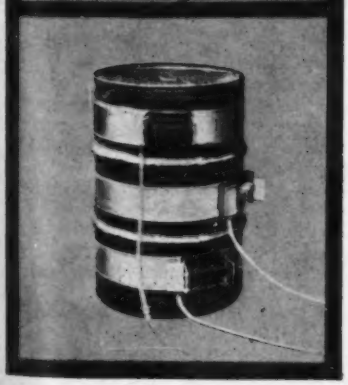
By virtue of its speed and computing capacity, the machine can control complex systems involving many variables, and is equally suitable either for continuous or for batch and sequence systems. For example, Argus can provide direct three-term control action on 100 or more loops whilst simultaneously providing computer logging and alarm facilities.

R. A. MORLEY,
for Chief Engineer.

Ferranti Ltd.,
GW Department,
Wythenshawe.

Electrothermal® DRUM HEATER





THE ELECTROTHERMAL DRUM HEATER is a NEW, robust unit specially designed to provide speedy application of heat to drums containing viscous or solidified materials such as Grease, Oils, Wax, Tar, Asphalt, Bitumen, Paint, Gelatine, etc. They can also be used for drying after washing.

SELECTIVE HEATING

By using single or multiple heaters it is possible to apply heat to any, or all, sections of the drum. This eliminates wasted heat when only a portion of the drum requires heating. They can be used on drums standing upright, lying on their sides or suspended.

The heaters are available for 200/250 volts with a wattage rating of 2 kW. for 40/50 gallon drums (Cat. No. PK 7003).

The amount of heat applied can be easily regulated by the use of control units, either single (Cat. No. MC 221 £3 5s. 0d.) or multiple (3) (Cat. No. MC 223 £9 2s. 6d.).

EASY TO HANDLE AND QUICKLY APPLIED

Send your order or enquiries to:

ELECTROTHERMAL ENGINEERING LTD., London, E.7. GRA 9911 Telex 24176.

PLANT EQUIPMENT NEWS

New Feeder Valves for Pneumatic Conveying

Two rotary feeder valves, specially designed to feed powdered and granular materials into pneumatic conveying lines, are now available.

The rotary feeder, type QNm, has been designed to overcome problems involved in conveying fine powdered materials in high-pressure lines. It consists basically of a robust casing carrying a chain-driven multi-bladed rotor, the driving shaft being carried in roller bearings. Material fed into the pockets between the blades is discharged at the bottom of the casing, where the blow-line is connected to the inlet and outlet ports. Air contained in the empty pocket is then discharged through a neutralising port to prevent it interfering with the discharge of stock from the bin.

Brass tips, inserted into slots at the periphery of each blade on the rotor, are rubber-cushioned at their base to maintain a constant seal at the point of contact with the rotor wall, and to provide automatic compensation for wear. The feeder's chain drive is transmitted through a shear pin arrangement, so that in the event of any foreign material becoming jammed in the valve, the shear pin breaks and thus prevents serious damage.

The feeder valve, type PNm, has been designed to achieve an uninterrupted flow of granular materials into a blowing line, while having sufficiently fine clearance to eliminate air leakage. Although it is based on the same fundamental principle as the type QNm feeder, the material being fed to the blow-line in this case passes through the base of the valve casing to a separate suitable connection mounted below. A neutralising port is included to feed back air which would otherwise cause puffing in the bin. A self-contained motor drive is fitted, the motor and gear reduction unit being mounted on the side of the valve.

They are being marketed as separate units, or in conjunction with the company's wide range of conveying systems. **Thomas Robinson & Son Ltd., Rochdale, Lancs.**

BCE 8803 for further information

Protective Coating of Heavy Equipment

The application of a comprehensive range of anti-corrosion and protective coatings to heavy equipment up to 5 tons in weight, under factory conditions, is now possible through a unique industrial service established in Manchester. This service will be most welcome, especially by the chemical, petroleum, food, textile and brewing industries.

Until now, the range of coatings available was limited and there has been an increasing and unsatisfied demand from producers of all types of equipment for facilities for the application of protective coatings to items in the 1-ton to 5-ton categories. The service, which is offered by West's-Loyne Ltd., includes technical advice in addition to surface preparation and application and curing of coatings.

Among the coatings applied are: epoxy resins (for the lining of vessels containing food, oil or chemicals); phenolics (water- and acid-resistant); synthetic rubber (abrasion resistance and corrosion prevention); P.T.F.E. (polytetrafluoroethylene—non-stick dispersion coatings for a variety of uses in industrial and domestic equipment); P.T.F.C.E. (polytrifluorchlorethylene—insulation and resistant to high temperatures and corrosive gases and acids); silicones (non-stick, heat- and chemical-resistant); metal spraying (zinc, aluminium, stainless steel); flame spraying (polythene, nylon, P.V.C.).

A temperature of 450°C can be attained at the new plant's gas-fired oven when needed for heat treatment of metal before P.T.F.E. coating. Provision is also made for curing coatings by hot air and infra-red heaters.

Other facilities available at the plant include the shot blasting of very large vessels in the open with mineral grit and, if required, work can be prepared by flame cleaning and power wire brushing. Pipes and ducting can be internally coated by spray or flow coating. Other types of application are by spray, brush and trowel. **West's-Loyne Ltd., Drewett Street, Miles Platting, Manchester, 10.**

BCE 8804 for further information

New Automatic Driers

AEI-Birlec are introducing a new series of adsorbers—the BZ series Autosorbers.

The new designs are fully automatic, dual tower plants, eminently suitable for

the continuous drying of compressed air and other gases. They have been arranged to be capable of using any of the commercially available adsorbents—activated alumina, molecular sieves, silica gel, Sorbead—and to employ them effectively to their best capacity according to the required circumstances.

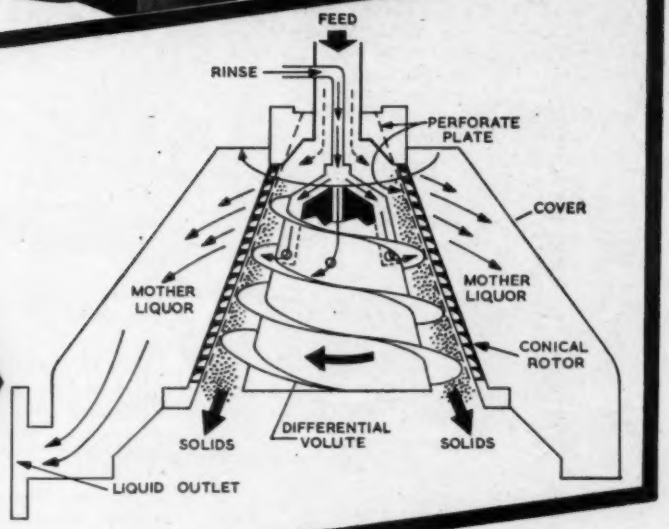
A further feature of the new plants, which derives from their ability to operate with molecular sieves, is their utility for the adsorption of carbon dioxide.

The adsorbers have been sized to provide compact designs for the capacities most frequently demanded by customers. Typical figures are in the range of 25-500 scfm at 100 psig or 5-100 scfm at atmospheric pressure.

These driers are lower priced, more compact and better looking than previous types and with a soundly based rating and performance. The floor area required is only about two-thirds of that needed by comparable previous models.

The more popular sizes in the range are now available from stock as standard

Now the **Super-Screen** joins the Sharples range



The arithmetic of success

A well proved Centrifuge pioneered in the European chemical and process industries — + Sharples manufacturing and chemical engineering experience = The New Sharples Super-Screen

● This is important news for everyone in the process industries. You ● ● can now have the best of both worlds. Installations in many parts of the world testify to its proven application on crystalline materials, but already our development men have found many exciting new applications. Write to-day for further information on this new centrifuge or about your own separational problems.

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PLANT EQUIPMENT NEWS

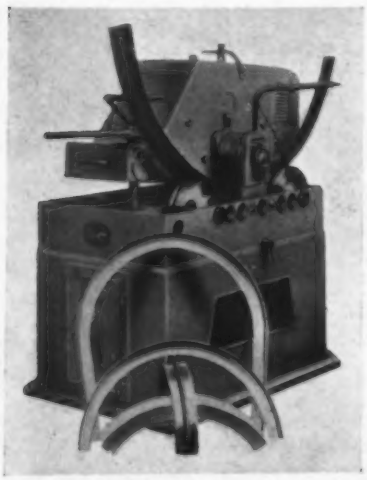
units fitted for electrical reactivation. By simple modification, these units may be converted to steam reactivation of flame-proof electric working. Optional extras are available for purge re-use. **Drier Department, AEI-Birlec Ltd., Tyburn Road, Birmingham, 24.**

BCE 8805 for further information

Continental Rolling Machine

The patent rights of the "Staffa-Universal", a unique, multi-purpose, rolling machine of continental origin, have now been acquired by a British company and the machine added to its range of bending and hydraulic equipment.

It is designed primarily for carrying out consecutive rolling operations in tube or rolled steel sections especially for boiler and steel fabrication work, and is the only machine of its type to be equipped with rolling suspension which allows continuous correction of secondary deformations. Other machines on the market normally use lateral rollers to square up the section during the bending operation, but it has been found that such squaring devices have only a limited action, and it follows that the sections leaving the machine are not exactly flat, and, in addition, the initial right angle is not retained. In the case of steel angles, the angle opens or closes and does not remain a right angle.

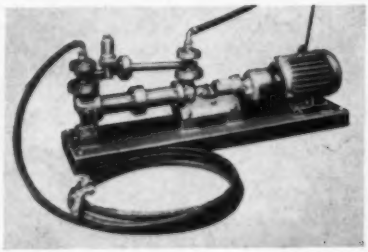


The standard fittings manufactured for each particular operation and to meet the problems of a particular cycle of work can be easily and quickly changed, resulting in a high rate of productivity on consecutive operations. The machine is of modern design and robustly constructed of welded steel throughout. It is supplied complete with a 4-hp, 440-volt, 3-phase motor, protected by a double-action circuit breaker. **Chamberlain Industries Ltd., Staffa Works, Argall Avenue, Leyton, London, E.10.**

BCE 8806 for further information

High-pressure Washing Unit

The Mono high-pressure washer is a neat and compact unit comprising a D26 Mono Pump mounted on a fabricated steel baseplate for use as a stationary or transportable unit. The standard unit is driven at 2800 rpm by a 3-hp 400/440 volt, 3 phase, 50 cycle a.c. totally enclosed motor. The pump is protected by a relief valve and is equipped with 25-ft lengths of suction and delivery hose. With the Kismet car washing gun fitted as standard, the pump delivers at a rate of 140 gph at 375 psi (maximum pressure 400 psi).



This simple unit is offered for such duties as tractor washing, washing down workyards, cleaning algæ from water storage tanks and removing fibre or dried pulp materials from rotary brushes, beaters or evaporator vessels. **Mono Pumps Ltd., Mono House, Selsforde Street, Clerkenwell Green, London, E.C.1.**

BCE 8807 for further information

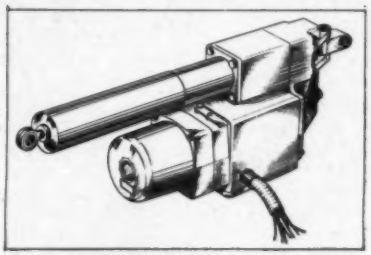
New Teleflex Actuator

The new Teleflex 750 actuator is an electromechanical device which has a 750-lb power output, a ram speed of 24 in. or 12 in. per min depending on the speed of motor used, an electrically-released twin disc brake, travel limit switches and position indication facilities. It will be widely used for the control of boiler dampers, valves, steel crucibles and furnace openings.

Load cut-out switches are arranged to enable the actuator to build up and hold a pre-set load on the object to which it is attached. In other words, the actuator is sensitive to the load being moved and has the power to maintain this load (for instance, against a valve seat). This load can then be held mechanically for an indefinite period without the need to maintain an electrical circuit.

Travel in either direction may be limited to suit requirements by built-in switches enclosed beneath a sealed cover, which are cam operated and adjustable on site. Indication of travel is provided by a pointer visible through a window in this cover. An electrically-released twin disc brake is a standard fitting and is used to check over-run and provide instant positive locking in any position of stroke.

All ball roller bearings, including ball bearing screw and nut, are provided for high efficiency and long, trouble-free life, over a wide range of operating temperatures. A plug-in handle is provided for use during setting up or in the event of electrical power failure.



Control position indication is available to requirements and consists of a variable reactance transmitter in unit with the actuator, coupled to a moving-coil receiver in the control panel. These components are supplied complete with a step-down transformer, the normal operating voltage being 12 V a.c. Where required, pilot lamps working at reduced voltage are supplied to indicate extremes of travel and/or load.

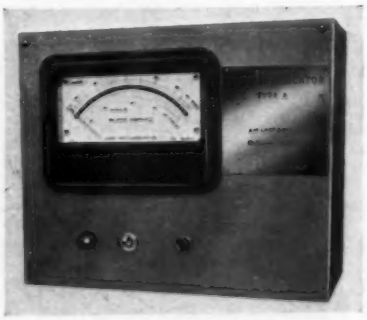
Control slidewires may be accommodated in place of the variable reactance transmitter to give feed-back control. Typical slide wires fitted cover the range from 0-100 ohms or 0-500 ohms with ±1% linear accuracy.

The actuator may be installed in any position and particular attention has been paid to the weather-proofing of the unit to seal it against the ingress of dust, dirt and water, rendering it completely suitable for operating out of doors under dirty conditions. **Teleflex Products Ltd., Basildon, Essex.**

BCE 8808 for further information

Humidity Indicator

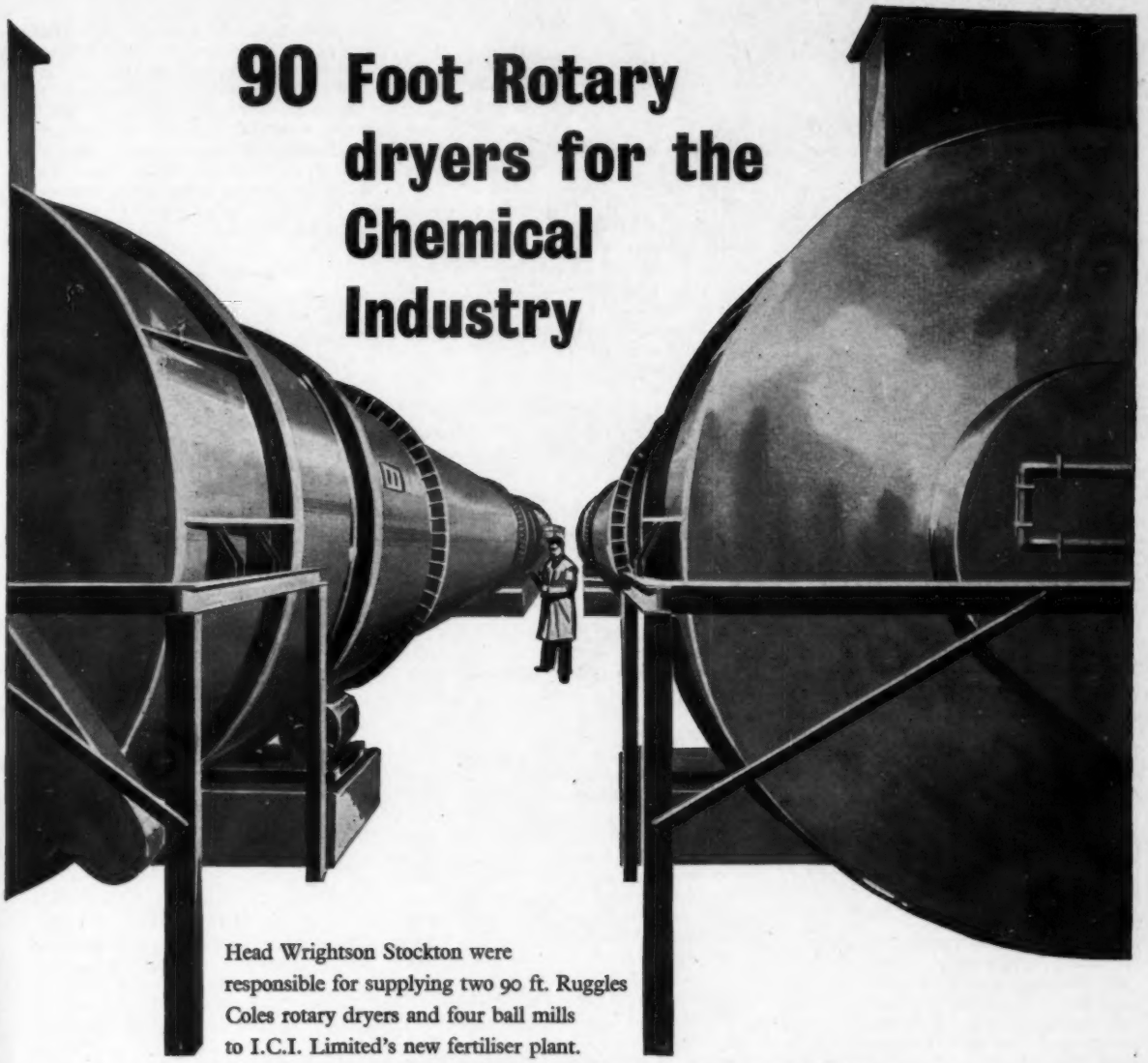
A humidity indicator using a plastic sensing element provides accurate and reliable humidity measurements over the range 10-100 per cent R.H. with excellent long-term stability. The robust sensing element is unaffected by most chemical vapours or by prolonged exposure to 100 per cent R.H. conditions. A multi-way selector switch enables a number of sensing elements to be connected, as required, to the indicator, so that humidity conditions at a number of remote posi-



tions can be quickly and easily checked. A chart recorder is also available for connection to a humidity indicator. **A. M. Lock & Co. Ltd., Oldham, Lancs.**

BCE 8809 for further information

90 Foot Rotary dryers for the Chemical Industry



Head Wrightson Stockton were responsible for supplying two 90 ft. Ruggles Coles rotary dryers and four ball mills to I.C.I. Limited's new fertiliser plant. The dryers are among the largest machines of this type ever to be built.

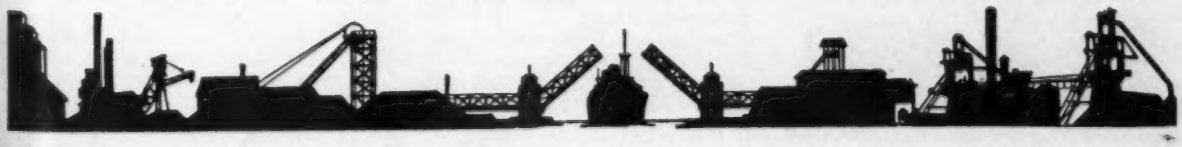
Head Wrightson have specialised in the design and manufacture of drying and grinding equipment for the Chemical and Mining industries for many years and have installed similar equipment in many plants in this country and abroad.

Please write for further information or telephone Stockton 65268.

HEAD WRIGHTSON STOCKTON LTD

STOCKTON-ON-TEES

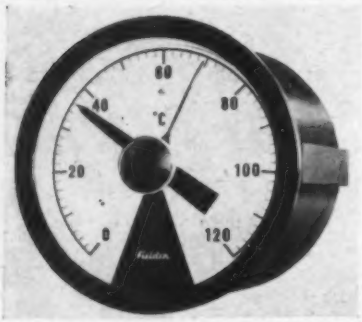
LONDON · JOHANNESBURG · SYDNEY · CALCUTTA



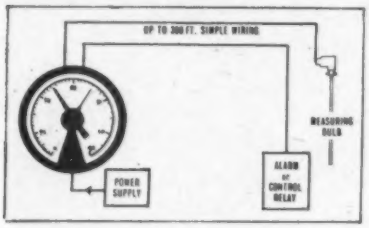
P.5729

PLANT EQUIPMENT NEWS

Temperature Indicator-controller



A new electronic temperature indicator-controller is now available in the Fielden Bikini range of instruments. It is housed in a 6-in.-diam. panel-mounting case and has a 13-in. scale calibrated in °C or °F in any of 73 standard ranges for temperatures between −200°C and +850°C. The instrument is completely transistorised for reliability and no maintenance is required. It can be operated from 12V d.c.



or the usual mains supply. The platinum resistance measuring bulb used with the indicator-controller is housed in a robust stainless-steel sheath of ¼ in. diam. and can be located up to 300 ft away from the instrument. The makers claim a calibration accuracy of ±0.5 per cent of the scale and a repeatability of 0.25°C on most ranges. **Fielden Electronics Ltd., Wythenshawe, Manchester.**

BCE 8810 for further information

Laboratory Conductivity Bridge

A recently-introduced mains-operated laboratory conductivity bridge covers the very wide range of measurement from 0.05 micro mhos up to 1 mho (20 megohms to 1 ohm) in seven overlapping ranges. It

is of value for normal laboratory uses and where measurements of very pure waters have to be made—for example, in transistor manufacturing processes.

Bridge balance is said to be precisely and clearly shown on the balance indicator meter. Variation in mains voltage or ageing of valves and components does not affect the accuracy, and a number of conductivity cells are available for use with the bridge. **A. M. Lock & Co. Ltd., Oldham, Lancs.**

BCE 8811 for further information

New Design Industrial Oil Burner

A reduction of 15% in fuel consumption is claimed for a new development in the design of self-proportioning oil burners for industrial applications. Other advantages claimed are constant air/oil ratio; automatic self - proportioning through a 5:1 range after initial setting; adjustable air nozzle; constant supply of atomising air with independent control of combustion air and spring loading of Vee slot, plug type, oil valve to ensure automatic compensation for wear.

The burner can be fitted to steam boilers working on semi-automatic high/low flame principle. The 5:1 or 6:1 turndown ratio meets most requirements.

The provision of twin vortex cups (the subject of new patents) and of a separate chamber for atomising air, which emerges at high velocity around the orifice of the oil nozzle, overcomes difficulties present in contemporary burners. The burner may be mounted at any angle to suit furnace requirements and is suitable for all grades of oil. **Premier Oil Burners, Eastbourne Street, Walsall, Staffs.**

BCE 8812 for further information

Low-temperature Refrigerator

Philips have introduced a new, four-cylinder, universal cooling machine, designed to meet the need in industrial processes for large-capacity, low-temperature refrigeration units.

It is based on the highly successful single-cylinder unit, well known in its forms of ready-made liquid air, liquid nitrogen and low-temperature cold-box equipments.

The new unit is intended for more general applications and is ideally suitable for direct condensation in distillation processes, liquid and gas stream cooling, and for allied industrial operations calling for refrigeration in the temperature range down to −200°C, and at a pressure range up to 450 psi.

The refrigeration machine is simple and foolproof in operation and extremely compact with a very advantageous power/weight/output ratio. Further, its high reliability factor makes it eminently suitable for long-term operation in continuous processes.

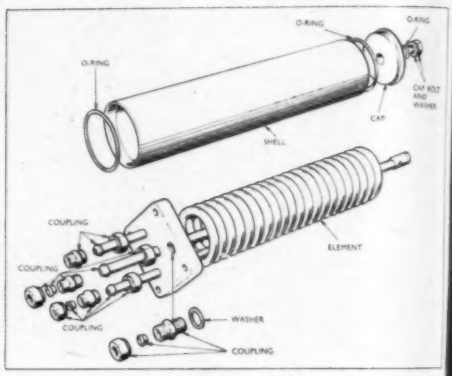
A special auxiliary unit is also available for the production of liquid air directly from the atmosphere. In addition, a fractionating column to produce liquid nitrogen is also under development. These new items have the same freedom from compressors and chemicals for air purification as their forerunners, the suction created by condensation being utilised to draw in the air supply. Moisture, carbon dioxide and other impurities are removed by a freeze-drying technique. **Research & Control Instruments Ltd., Instrument House, 207 King's Cross Road, London, W.C.1.**

BCE 8813 for further information

New Heat Exchanger

Primarily developed to form an integral part of cooling systems for mechanical shaft seals, the Crane "Heat Dissipater" is also capable of application as a heat exchanger in its own right, for many other purposes.

It has a capacity of 10,000 Btu/hr, but two or more units can be used either in series or in parallel, when the rate of flow and the required temperature drop exceed the capacity of a single unit.



With the exception of the connections for the coolant—which are mild steel, cadmium plated—the whole of the metal component parts of the "Heat Dissipater" are manufactured from stainless steel.

The "Heat Dissipater" is a particularly compact unit, highly efficient in operation, and it provides a considerable degree of flexibility in the method of mounting in relation to the particular equipment with which it is to be used.

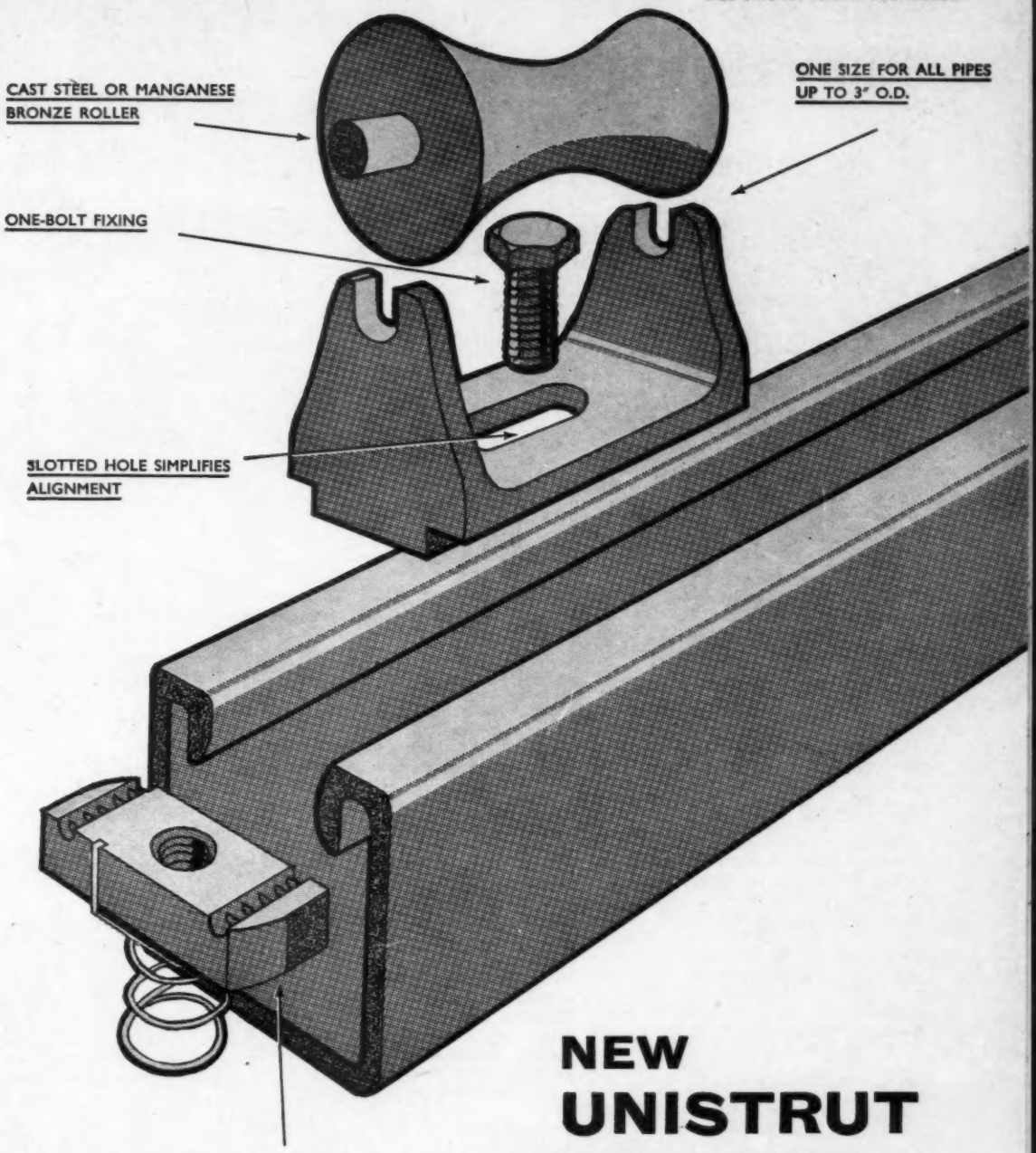
It is designed for pressures up to 2000 psi for the product and 150 psi for the coolant.

The firm's information bulletin No. 23 gives full details of design and construction plus recommended flow rates for both product and coolant, which range between 20 and 120 gal/hr. **Crane Packing Ltd., Slough, Bucks.**

BCE 8814 for further information

New Liquid Meter

A versatile new liquid meter which can be used independently, or as the brain centre of a complete metering system for processes using liquids of different viscosity, acidity, alkalinity and temperature, is now available. It is the "Unipulse". four models of which are available with minimum and maximum flow rates ranging from 5 to 300 and 100 to 12,500 imp gal/hr respectively.


CAST STEEL OR MANGANESE BRONZE ROLLER
ONE SIZE FOR ALL PIPES UP TO 3" O.D.
ONE-BOLT FIXING
SLOTTED HOLE SIMPLIFIES ALIGNMENT
UNISTRUT SELF-LOCATING NUT

NEW UNISTRUT ONE-BOLT PIPE ROLLER

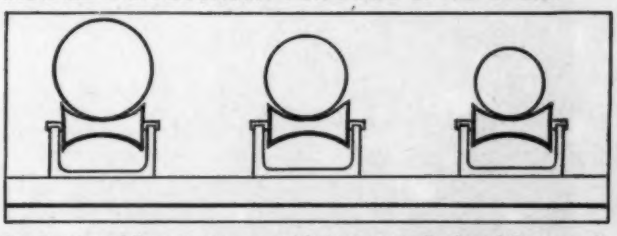
Small pipe installation is now even faster and cheaper with the Unistrut system. This new roller is particularly easy to attach to the Unistrut support framing and also facilitates alignment of the runs.

A single bolt and self-locating nut fixes the chair to the open side of a Unistrut channel, in which it is located by projecting lugs. The roller rests on the chair and is designed to allow free movement of the pipe.

Roller and chair are normally of cast steel; a manganese bronze roller is supplied for use with copper pipe.

WJI 713

INSTALLATION ECONOMY FOR PIPES UP TO 3" O.D.

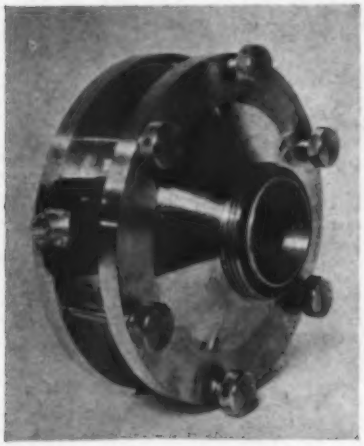


For drawing of the new component to bring your Parts catalogue up to date, or general information on the Unistrut system, please write to

UNISTRUT DIVISION OF SANKEY-SHELDON LIMITED

43-45 Broadwater Road, Welwyn Garden City, Herts. Tel: Welwyn Garden City 6321 (4 lines)

PLANT EQUIPMENT NEWS



An outstanding feature of this meter is the ingenious electro-magnetic system used to transmit liquid flow data to remotely-positioned indicators and control devices. It operates on the rotary piston principle, where the piston revolutions are counted electro-magnetically, thus eliminating the need for stuffing boxes, rotary seals, etc. Efficient and accurate operation at the lowest rates of flow are ensured by the design of the pick-up used, which keeps the signal amplitude constant regardless of flow rate.

The electrical impulses can be transmitted to electro-magnetic counters summating the amount of liquid passed, to Dekatron tubes preset by means of rotary switches or punched cards, to a rate of flow indicator and other devices. With a constant head or constant pump output, the Unipulse can be calibrated to within an accuracy of ±0.25%. **Measurement Ltd., Taneside Works, Dobcross, Oldham, Lancs.**

BCE 8815 for further information

Chemical-resistant Treated Plywood

A specially-treated, waterproof plywood has solved a long-standing problem in the Randak tanning plant of R. & A. Kohnstamm Ltd., Beckenham. Forming the access doors of large tanning drums, the plywood is successfully resisting chromic acid, lime and chemical dye solutions that have made short work of ordinary timber and even solid metal.

The doors are a new and unusual use for Permaply, the resin-impregnated plywood. They are formed of Permaply sheet framed in gunmetal and secured by stainless-steel bolts; solid brass fixings originally tried corroded and soon became useless. Dimensions are 27½ in. by 18 in.

The inner surface of the doors, inside the drums, is submerged almost continuously. Under this treatment, doors made from ordinary wood quickly began to swell, warp in their frames, and finally split. The chemically-treated Permaply has remained flat and unbroken after nearly a year's exposure—a remarkable demonstration of the material's stability and resistance, without maintenance, to the most extreme conditions. **Venesta Plywood Ltd., Vintry House, Queen Street Place, London, E.C.4.**

BCE 8816 for further information

Cold Paint Stripping Compound

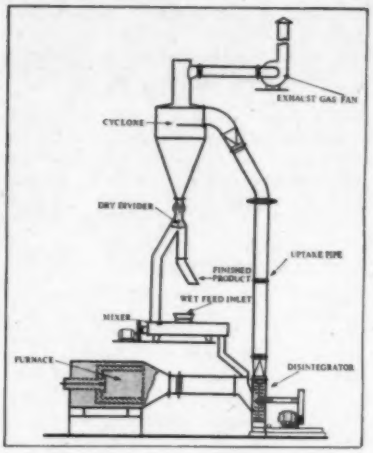
Magnus 701-M is a specially formulated solvent compound for cold cleaning of aircraft, diesel, locomotive, and all other parts where carbonised oil, gum and fuel residues must be removed. It is also effective for the removal of residues from rubber matrices, paint stripping and similar applications. Experience indicates that this product will deal satisfactorily with many of the epikote-type paints.

It contains its own seal, and water additions should not be made. It is used at room temperature and should not be heated. When sludge accumulates, the solution should be allowed to settle overnight and then poured off into another container so that the sludge can be removed from the tank. It is important that the entire solution be re-used so that the ratio of seal remains constant. Where long-term protection against oxidisation is necessary, work should be treated in a dewatering solution, Magnus Protectoline. **Magnus Chemical Co. Ltd., Salisbury Road, Industrial Estate, Uxbridge, Middx.**

BCE 8817 for further information

Raymond Flash Drying Systems

Raymond flash drying systems now introduced to this country for the first time are used to remove definite amounts of moisture from damp, granular or fibrous material. The material is circulated in a hot, turbulent gas stream, causing the rapid transfer of heat and evaporation of moisture. When simultaneous drying and grinding are required, a disintegrator or pulveriser is included in the system. The finished product is separated, cooled and conveyed in a dust-free plant operating under suction, and its dryness and particle size may be accurately controlled. These systems are widely used for drying materials such as wet coal cake and sewage sludge, and also for the preparation of chemicals, foods and fertilisers. They are designed to accomplish drying under three distinct conditions: drying without disintegration and drying with disintegration, and drying and pulverising.



Illustrated is the system for drying with disintegration showing direct oil firing, cage mill, mixer and dry divider. **International Combustion Products Ltd., 19 Woburn Place, London, W.C.1.**

BCE 8818 for further information

Automatic Control Batching Timer

This special "Rodene" timer has been designed to control batching and mixing plants in which the amount of each constituent is decided by the time the hopper containing it is opened.

As all the materials are delivered to a mixer of fixed capacity, it is best to think of the quantity of each as a percentage of that capacity and accordingly these timers are calibrated in percentage.

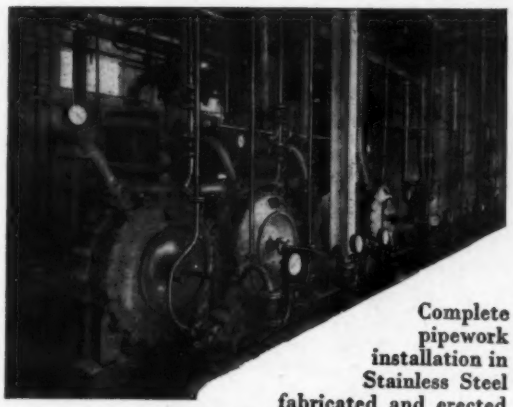
If only to prevent overfilling of the mixer, the timers should always be set so that the total of their dial readings equals 100%. To assure this, each timer has geared to its setting pointer an accurate potentiometer and these can be interconnected so as to show on a moving coil meter the total of their settings. It can also be arranged that the plant cannot be run unless this meter shows 100%.

These timers have contacts that allow many methods of operation, but for this purpose they can be connected to start on receipt of a pulse; to close a contact for the timed period; and to give out a further pulse at the end of the timed period which can start the next timer in the chain.

BCE 8751 for further information

Stainless Steel . . .

tanks, coils and pipework by *Jenkinsons*



Complete pipework installation in Stainless Steel fabricated and erected on site by JENKINSONS.

Also fabricated and erected on site by JENKINSONS, Stainless Steel ducting 9 ins and 18 ins dia. with special smooth finish both internally, to minimise friction losses, and externally, to improve corrosion resistance.

W. G. JENKINSON LTD.
ARUNDEL STREET; SHEFFIELD 1.
Phone 27438/9

BCE 8752 for further information

A metering pump

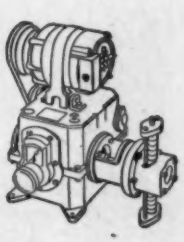
for Precision, Versatility, Durability

Metripump Type "G"

This Metripump is a precision, variable stroke metering pump of the positive displacement type, the length of stroke of which can be varied from zero to maximum either whilst the pump is in operation or at rest. A wide range of pump heads is available in different materials and with different designs of valve gear.

There is no substitute for experience in recommending metering pumps for specific problems.

Metering Pumps Limited



21 The Mall, Ealing, London, W.5.
Telephone: EALing 6264 (PBX)

PLANT EQUIPMENT NEWS

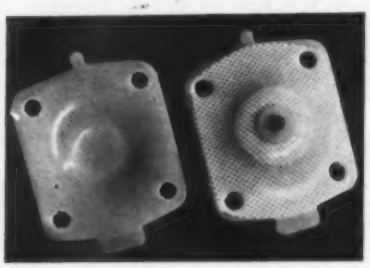
Should the timers reset because of mains failure during batching, there would be the great inconvenience of a batch which could not easily be completed.

This unwanted resetting need not occur when these batching timers are used as, although their motors depend on a.c. for synchronous running, their clutches can be made for d.c. operation and if they are fed from a small floating battery a batch interrupted by mains failure will be completed accurately on resumption of mains. **D. Robinson & Co. Ltd., Gunnersbury House, 717 London Road, Hounslow, Middx.**

BCE 8819 for further information

"Terylene" in Valves

"Terylene" is being increasingly used by the rubber industry as a reinforcement for conveyor belting, "V" belts and industrial hose. Now a leading U.K. manufacturer of diaphragm valves has pioneered and developed an entirely new use for it —as a reinforcement for diaphragms.



Extensive tests proved that "Terylene" was stronger, lasted longer and was generally more satisfactory than the materials previously used for this job. As a result, most of the valves made by this company are incorporating a "Terylene" reinforcement in their diaphragms.

Illustrated, an "A" type Saunders valve diaphragm of translucent material shows the "Terylene" reinforcement. **Saunders Valve Co. Ltd., Cwmbran, South Wales.**

BCE 8820 for further information

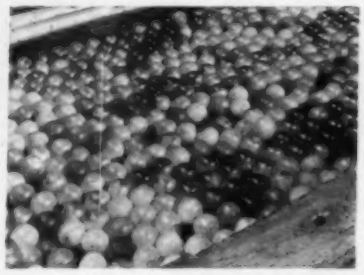
Rigid Polyethylene Ball Chroffles for Plating and Pickling Baths and Oil Storage Tanks

Rigid ball chroffles, spherical and of approximately 1½ in. diameter, made from Rigidex high-density polyethylene, are now available for use in plating and pickling tanks.

They float on the surface of the liquid and form an inert blanket which minimises spray and splashing of dangerous or objectionable solutions, thus reducing busbar and ducting corrosion and providing an additional safeguard for plating shop staff.

The chroffles reduce heat losses from the bath surface and can save as much as 12% of the heating normally required.

Due to their shape, ball chroffles "take up" uneven contours or projections on the articles being processed and thus



maintain uniform coverage of the solution. Chroffles made from Rigidex are suitable for temperatures of up to 200°F and are resistant to most acids and alkalis. They are also resistant to oils and are being evaluated as a seal for oil storage tanks to prevent losses due to evaporation.

The illustration shows a layer of ball chroffles blanketing the surface of a large chrome bath used for facing electros and original printing plates at the works of Hazell Watson & Viney, printers, of Aylesbury. **W. Canning & Co. Ltd., P.O. Box 288, Great Hampton Street, Birmingham, 18.**

BCE 8821 for further information

New Publications

In a pamphlet, "Re-thinking Thermal Insulation", it is pointed out that there are four main reasons for insulation. These are to save money, control processes, prevent condensation and protect personnel and equipment. The pamphlet lists cases where surface temperature should determine thickness, then goes on to the more frequent case where the criterion is economic thickness of insulation. **National Insulation Manufacturers Association, 441 Lexington Avenue, New York, 17, N.Y., U.S.A.**

BCE 8822 for further information

The principle of transmitting power by means of a fluid coupling was known as far back as 1905, but the problem of turning this principle into wide practical use has mainly been achieved by years of development and experience in controlling the internal circulation of oil. This is done in a variety of ways to suit the wide range of duty of many types of machines, some of which are described in a pamphlet, "Vulcan-Sinclair Fluidrive", obtainable from **Fluidrive Engineering Co. Ltd., Isleworth, Middlesex.**

BCE 8823 for further information

Precious-metal thermocouples are the subject of the latest publication from the Baker Platinum Division of Engelhard Industries Ltd. Platinum *v.* platinum-rhodium thermoelements are the most widely used in industry, and calibration tables are given for these and many other types of precious metal couples that have been developed by the company for special applications. Two important developments in the field of high-temperature measurement are also described. One of these is a new thermoelement platinum having a fibrous structure which resists recrystallisation at high temperatures and therefore resists grain growth. It is claimed that the life of this "fibro" platinum is several hundred times greater than that of the conventional type. The other development is an integral sheath thermocouple which is said to have a far greater resistance to shock than conventional sheathed assemblies. It consists of a flexible metallic outer sheath (approximately $\frac{1}{16}$ in.) and insulated from the thermoelements by a pure oxide refractory. **Engelhard Industries Ltd., 52 High Holborn, London, W.C.1.**

BCE 8824 for further information

A four-page leaflet (Publication No. 200) describes and illustrates materials handling plant made by Holdan Engineers (London) Ltd. The company has considerable experience in the field of positive and negative pressure pneumatic handling with a wide variety of materials such as fly-ash, pulverised coal, cement, plastic granules, etc. The company will also design and install comprehensive processing plants which incorporate such features as continuous weighing heat exchange, and batching and weighing equipment. **Holdan Engineers (London) Ltd., 119 Victoria Street, London, S.W.1.**

BCE 8825 for further information

The history, development and correct application of the complete range of 150 eutetic low-temperature welding alloys and fluxes are described in the newly revised Maintenance Welding Data Book published by Eutetic Welding Alloys Co. Ltd. This company's metal joining process combines the advantages of the low heat input of brazing methods with the higher strength of welding. A bond is produced by the formation of a surface alloy between the base metal and the filler metal, the formation of the alloy being caused by the diffusion of the eutetic welding alloy or filler metal into the base metal. **Eutetic Welding Alloys Co. Ltd., North Feltham Trading Estate, Feltham, Middlesex.**

BCE 8826 for further information

"I.C.I. Finishing Facts" deals with a wide range of products employing the firm's finishes or techniques. It includes an article, "Spinning and Thinning". describing how paint samples are spun in the latest range of laboratory apparatus developed by Paints Division for quick and accurate thinning which can be used in place of the flow-cup. **I.C.I. Ltd., Paints Division, Slough.**

BCE 8827 for further information

"Fairey Review", Vol. 3, No. 3, includes an article on the Fairey Microfilters which were originally designed to filter the oil in aircraft hydraulic power control systems. Now they are used wherever high-grade filtration is required — in machine tool circuits and in filtering anything that flows, from nuclear gas to tar. **Fairey Co. Ltd., Bruton Street, London, W.1.**

BCE 8828 for further information

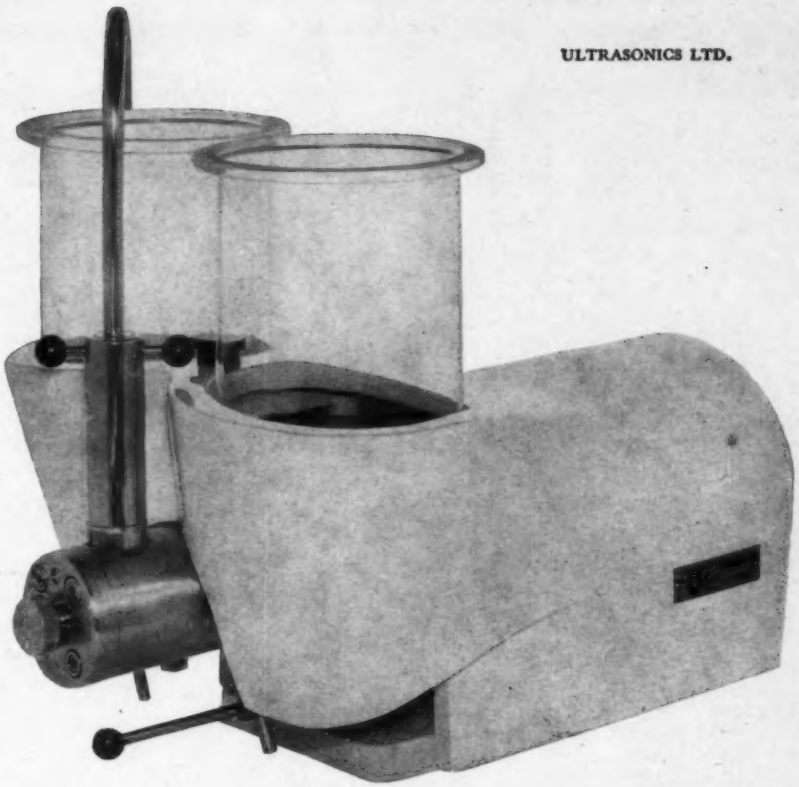
BCE 8753 for further information

ULTRASONICS LTD.

This ultrasonic homogenizer offers the easiest, most convenient and efficient way of making emulsions and dispersions.
Minisonic Model 3 is made in stainless steel with built-in glass vessels and perfect finger tip control valve.
Developed on the experience of over a thousand installations of the Rapisonic, it is an advanced and reliable machine, sold at a sensible price.
Details on request from *Ultrasonics Ltd.*, Westgate, Otley, Yorkshire.

THE NEW MINISONIC

model **3**



Continuous vertical retort structure and supporting steelwork, at Lostock Hall Works, Preston; Denso protected by The Denso Contracting Department. Photograph by courtesy of The North Western Gas Board.

DENSO

prevents CORROSION

. . . the sure, certain, economical answer to most corrosion problems is
The DENSO anti-corrosion SERVICE

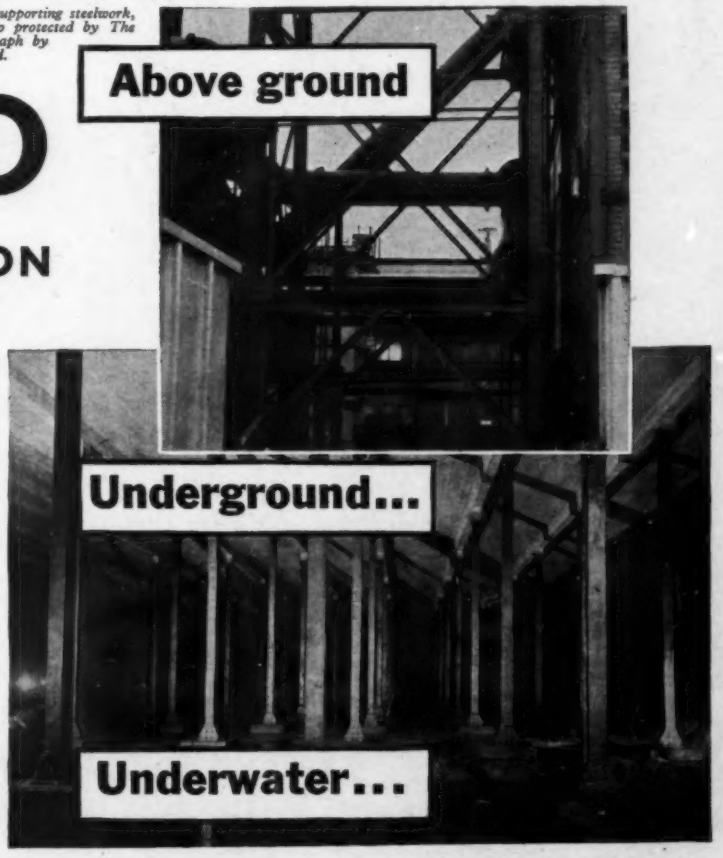
specification and estimate from

WINN & COALES LTD

LONDON	*Tel: GIPsy Hill 7511*
MANCHESTER (also Contracting Dept.)	*Tel: Sale 8271*
BELFAST	*Tel: 56623*
DUBLIN	*Tel: 61768*

Agents throughout the Commonwealth

To all our friends we wish the compliments of the Season



Roof stanchions and other steelwork in this main reservoir Denso protected by the Denso Contracting Department. Photograph by courtesy of Widnes Corporation Waterworks.

BCE 8754 for further information

World of Chemical Engineering

Fresh Water from Sea Water

A £257,000 sea water distillation plant was recently opened at Guernsey in the Channel Islands by Mr. R. A. BUTLER, Home Secretary.

The plant will produce ½ million Imperial gallons of fresh water daily to supplement the supplies from the island's reservoirs and catchment areas. It is being studied with special interest by water engineers, as it is the first of its kind in the temperate zone.

There is nothing essentially new about salt water distillation plants. They have been manufactured for shipboard use since the 1880s. During the past few years, however, great technical progress has been made in the construction of land-based plants. G. & J. Weir Ltd., of Glasgow, the builders of the plant, have recently built units in such arid or semi-arid places as Curaçao, Aruba, Gibraltar, Andaman Islands, Egypt, Kuwait, Aden, Lobitos and the Bahamas. Sea-water conversion units with a capacity of up to five million gallons per day can be built, although the largest Weir has produced so far is a one-million-gallon unit. Units can be grouped together, however, to give any capacity desired.

The distillation process takes place in an evaporator 69 ft long, 19 ft wide and 18 ft high, which is internally subdivided into a number of flash and preheater chambers.

The incoming seawater passes through heat exchangers in the plant's forty flash chambers, after which it is further heated by exhaust steam from a steam engine.

In the flash chambers the atmospheric pressure is reduced by means of an air ejector and the hot sea water in its passage through the plant flashes off salt-free vapour due to this partial vacuum. The vapour is condensed on the heat exchangers mentioned above as pure distilled water, which is collected and pumped to storage.

De-aeration of the incoming sea water and chemical injection equipment ensure that corrosion and scale formation are kept to a minimum, enabling the plant to be run for long periods.

£10-million Project in South Wales

British Hydrocarbon Chemicals Ltd. are planning a major extension of their manufacturing activities at a new location in South Wales. The proposed site, of several hundred acres, will be within a short distance of the British Petroleum Co.'s refinery at Llandarcy near Swansea.

The company is already actively engaged in the petrochemicals industry at Grangemouth, receiving its supplies mainly from the adjacent B.P. refinery. The process at the new plant is expected to follow that at Grangemouth, where a variety of chemicals serving as raw materials for other industrial processes are made by "cracking" and processing the feedstocks obtained from the refinery.

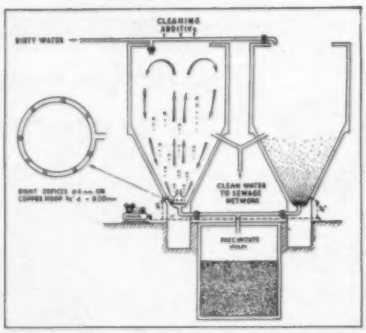
Such a project can only be initiated on a large scale and, while no capital authorisations have yet been approved, initial investment may well be about £10 million.

British Hydrocarbon Chemicals Ltd. is jointly owned by The British Petroleum Co. Ltd. and The Distillers Co. Ltd.

Compressed Air Solves Trade Waste Problem

Trade wastes are a problem in all expanding cities. The recent growth of Athens brought the tanneries of Cavada Brothers Ltd. within an inhabited area, and the firm was requested by the city hygiene department to purify the effluents from the factory before they were discharged into the municipal sewage system.

Tannery waters contain, in addition to germs and dirt, large quantities of albumen (from the animals' blood), gelatin (from the skin), proteins and remains from tannate substances such as $Ca(OH)_2$ NaCl, Na_2S and Na_2SO_4. They also smell very disagreeable.



At first, they tried to filter their trade wastes, but without success. Next, chemical purification assisted by mechanical agitation was attempted, but was abandoned because oxidation was not complete, corrosion resulted in heavy maintenance costs and enormous power was needed to drive the agitation machinery.

The problem was brought to the attention of Atlas Copco (Greece) Ltd., who suggested the use of compressed air as a purifying medium. With the agreement of the chief chemical engineer of the tannery, they helped him to design two large concrete tanks each of 5250 cu ft capacity. Compressed air mains were connected to the bottom conical orifices of these tanks.

The system of cleansing is as follows: the tannery effluent is pumped into the tanks and mixed with chloride of lime and chromate salts. The mixture is agitated for six hours by compressed air. The mixture is left to settle until the cone of the tanks is filled with precipitate and the water above is odourless and pure. Precipitation period is between one and two hours. The compressed air not only agitates the water-chemical mixture, but also provides oxygen for complete oxidation. The method has been approved by the Athens hygiene department.

After settlement, the purified effluent is piped off to the sewage main and the precipitate stored in an underground tank and removed periodically for dumping in an unpopulated part of the countryside outside the city.

The air is conveyed from the air receiver to the tanks by a ¼-in. pipe ending in a ¼-in. copper hoop (one inside each tank) perforated with eight 4-mm holes.

Oil from Coal in South Africa

Claimed to be the largest in the world, Sasol, the South African oil-from-coal plant, is spending another £3½ million on a development scheme to increase speed and production. It will be completed towards the middle of 1961. Last year's production of Sasol petrol was 35 million gallons, and after the new developments this should be expanded to 40 million gallons per year. The plant also produces 110 million cu ft of pure gas daily, and serves more than 150 customers in the chemical field with basic products.

Petrochemical Plant in Spain

An agreement has been reached between Dow Chemical International Ltd. and Union Quimica del Norte de Espana to construct a petrochemical complex in Spain. The Spanish Government has given its approval to the joint venture.

The development plan includes the construction of a cracking unit which will produce ethylene and propylene. The resulting C4 fraction will be further processed to recover butadiene. Effluent gas will be used instead of gasefied carbon materials in an existing methanol plant.

These new basic raw materials will then be used by the Spanish company for the manufacture of a wide range of chemicals and plastic materials, such as polyethylene, polypropylene, polystyrene and others.

Under the terms of the agreement, the Spanish company will be entitled to technical knowledge and engineering and marketing assistance from Dow.

German Chemical Factory for India

A recent agreement between the Indian Government and a consortium of four West German firms provides for the establishing of chemical works in the vicinity of Bombay. The works will manufacture chemical intermediates and chemical products which would provide the basis for the production of basic organic chemicals for the manufacture of pharmaceuticals, synthetics and dyestuffs.

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The German firms Bayer, BASF, Hoechst and Uhde will supply the know-how, will assist in the planning and erecting of plant and in the purchasing of machinery and equipment. It is estimated that the total cost of this project would amount to over £9 million, including £3 million for machinery and imported equipment, patent rights and services of the advisory personnel. A joint company, comprising the Indian Government and the three first-mentioned German firms, will be formed, and the German firms will receive shares of the new company as a remuneration for their services.

Beer by Pipeline

Approximately 50 barrels of beer can pass hourly through any main in an installation consisting of over a mile of glass pipeline recently installed by QVF Ltd., chemical engineers in glass, in a new tank-storage building at the Stratford on Avon brewery of Flower & Sons Ltd.

Mr DAVID COMYN, head brewer, said: "We have used 2-in.-bore glass pipeline because it is more economic than stainless steel or copper, easy to clean and ideal for observation purposes."

Beer is piped through two QVF pipelines, or racking mains, from the fermenting room direct to any one of ten stainless-steel storage tanks of 160-barrel capacity, where it is kept at a temperature of 55°F for a conditioning period.

Tanks are pressure vessels capable of working to 30 psi. Beer is subsequently piped from the bottom of the storage tank to the chiller inlet. It passes through one of two plate heat-exchangers, which reduces its temperature to 32°F. From the chillers the beer is piped back to the original tank. The chilling system is, in effect, an automatically-controlled closed circuit.

After a further conditioning period, final process is filtration. Beer is filtered into one of three bright beer tanks to await passage to the metal-keg filling machines.

"Powders in Industry" Symposium

At the end of September the Surface Activity Group of the Society of Chemical Industry held a symposium on "Powders in Industry: Properties and Principles of Application" at The Royal Institution.

Fine particles occupy a special position in research and technology today. The traditional classification of matter into solid, liquid or gas does not take account of the special properties or particulate matter. "As we look at things with closer examination and with closer approach to practical technology, it is seen that matter in powder form is a solid state which has many properties partaking of some characteristics of liquid or gases," wrote SIR ALEXANDER FLECK in a message for the symposium.

SIR ALEXANDER FLECK, who is this year's President of the Society of Chemical Industry, opened the symposium, which was attended by some 300 scientists, of whom several had come from abroad.

There were altogether 31 papers. Papers were briefly introduced in groups of three to six and nearly the whole time was therefore available for discussion. The first group of papers dealt with "Principles of Production" and was introduced by DR. M. G. FLEMING of the Royal School of Mines.

The next group of papers dealt with "Properties of Powders" and was introduced by PROF. N. K. ADAM with PROF. D. H. EVERETT in the chair. Amongst the papers in this group was one by PROF. B. V. DERJAGUIN, of the U.S.S.R. Academy of Sciences, "On the Influence of Liquid Films on Adhesion between Particles of Powders".

Next followed papers on the "Utilisation of Powders in Industry", each paper, of which there were 18, dealing with a different technology. For instance, DR. S. H. BELL dealt with "Pigments and Fillers for Use in Paints", DR. J. R. SCOTT with "Fillers and Pigments for Use in Rubber and Plastics", P. UTTENTHAL with "Building Cements" and so forth. There were papers on Powder Metallurgy, Detergent Powders, Pesticides, Coal, and other industrial uses, including a paper by PROF. P. G. KIHLSTEDT from Stockholm on "Mineral Dressing" and by DR. J. A. BOTTEMA from The Hague on "The Properties of Powders Utilised in Drilling Fluids".

The last section consisted of three papers which represented a summing-up of the symposium and an assessment of future research requirements.

Electronics use Hydrofluoric Acid

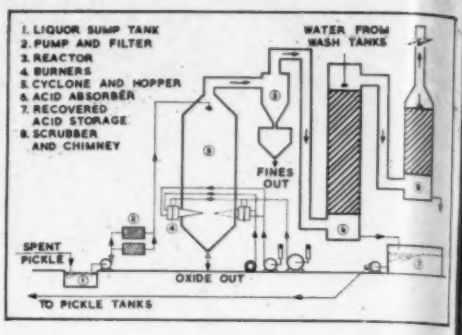
Hydrofluoric acid has found two main applications in the electronics industry. First, it is used in the processes for producing silicon and germanium, two metals used extensively by electronic device manufacturers; and, secondly, the manufacturers themselves use it for etching transistors and other semi-conductor devices.

The demand for hydrofluoric acid from this source has increased so much that James Wilkinson & Son Ltd., specialist producers of fluorine chemicals, have taken urgent steps to increase production. More hydrofluoric acid of the highest purity will be available early in 1961, when a new plant now under construction comes on stream.

British Plant for Israel

Nordac Ltd., one of the Woodall-Duckham Group of Companies, has been granted a licence by the Israel Ministry of Development to sell and construct plant in accordance with the Aman patented process. The process was invented in Israel originally as a means of obtaining hydrochloric acid and magnesium oxide from Dead Sea brines. It is a continuous spray technique for the hydrolysis of metal salts, being particularly suitable for the recovery of hydrochloric acid from spent pickle liquors and other chloride effluents. In this application acid consumption may be cut by over 90 per cent, the recovered acid of up to 20 per cent HCl being ready for re-use.

The reaction takes place in a vertical furnace or reactor directly heated by the combustion of oil or gas in the lower part. The feed liquor, slurry or melt is fed



through atomisers into the top of the reactor.

The Aman process will cut acid costs and solve many effluent problems. Nordac Ltd. have a pilot plant available for the testing of liquors.

New Process for Gas Purification

A process developed in the past eighteen months by a team of North Western Gas Board technologists and the Research Department of The Clayton Aniline Co. is the subject of a world-wide patent application.

Known as the "Stretford" process, the new process overcomes many of the shortcomings of conventional processes for the removal of H_2S from gases such as the iron oxide box system. For example, gas treatment by the latter method costs about 0.3 pence per therm, whereas at the two plants where the new process has been in operation (Rochdale Road and Whitchurch) the cost has been approximately 0.2 and even as low as 0.1 pence per therm, the market price of the recovered sulphur having a bearing upon the cost of purification.

Essentially, the "Stretford" process consists of treating the gas with a mixture of sodium salts, dissolved in water, of two special forms of anthraquinone di-sulphonic acids. These are the "2-6" and "2-7" forms, whose molecular structure makes them particularly reactive.

There are four main stages in the purification cycle of the process.

(1) The gas is contacted countercurrentwise by the anthraquinone di-sulphonic sodium salt solution, an operation which removes H_2S from the gas.

(2) The solution is retained in a reaction tank long enough for its hydrogen sulphide content to react with the carbonyl radicles present to yield free sulphur and the corresponding hydroquinone.

(3) The solution is pumped to a tower through injectors which entrain sufficient air to regenerate the original quinone.

(4) The solution, now containing free sulphur in suspension, is filtered for removal of the sulphur before reuse.

Potential applications include the treatment of refinery gases purchased by the chemical and gas industries, purification of liquid products of the oil industry contaminated with hydrogen sulphide, purification of synthesis gas and the removal of hydrogen sulphide and carbon bisulphide from air in the viscose and transparent paper industries.

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